# SEWAGE WORKS JOURNAL

VOL. IX JANUARY, 1937 No. 1

## *Special Articles*

A Note on High-Rate Trickling Filters—Imhoff

Trickling Filter Loadings—Hall-Hatch

Temperature and Time of Digestion—Fair and Moore

Value of Returned Chemical Sludge—Rudolfs and Gehm

Elutriation of Digested Sludge—Keefer and Kratz

Studies of B.O.D. Dilution Water—Nichols and Lee

W.P.A. Achievement at Dayton—Tatlock

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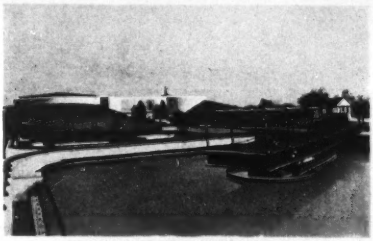
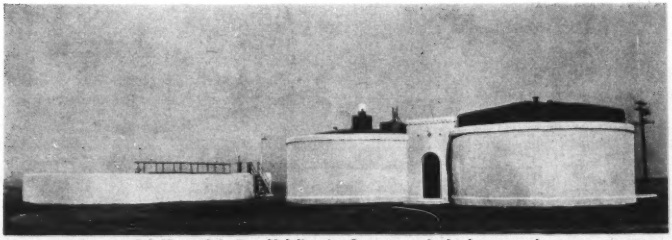


*Cedarhurst, L. I., Dorr Multdigestion System in background*

*Fargo, N. D., Dorr Multdigestion System, completely under ground*



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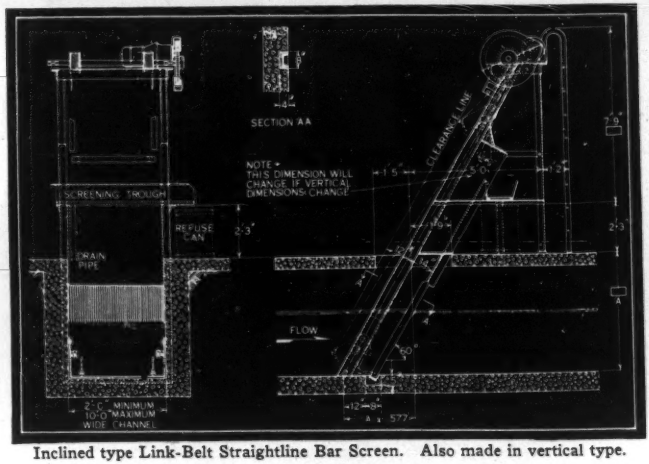


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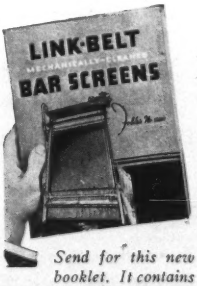


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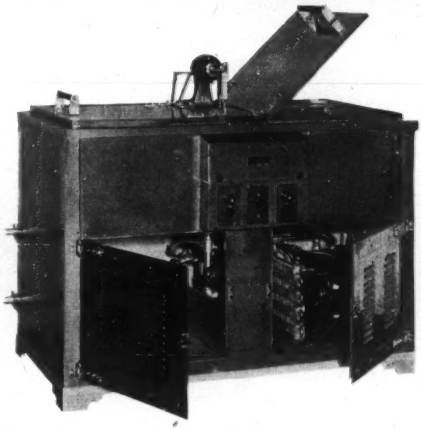

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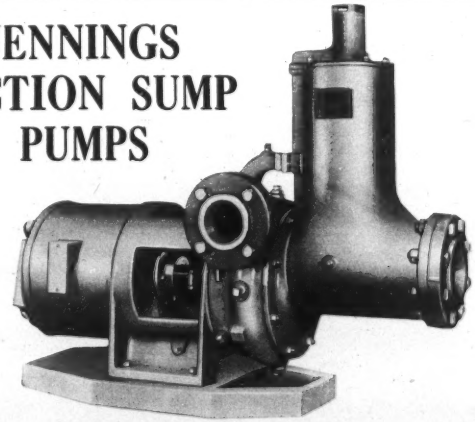

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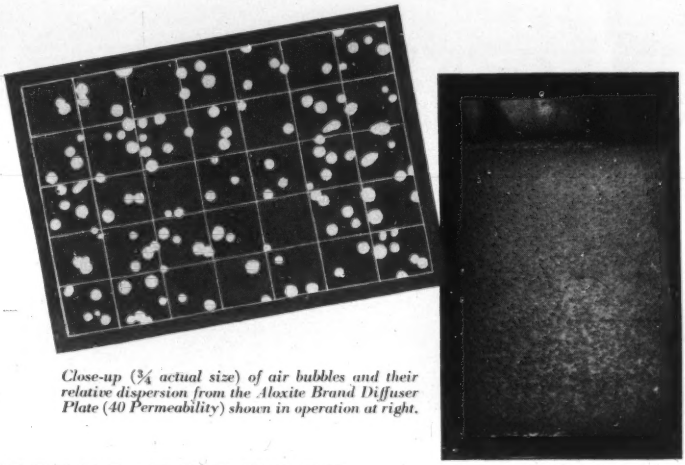

*Close-up (¾ actual size) of air bubbles and their relative dispersion from the Aloxite Brand Diffuser Plate (40 Permeability) shown in operation at right.*

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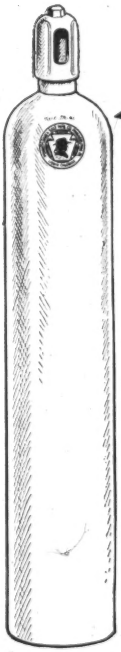

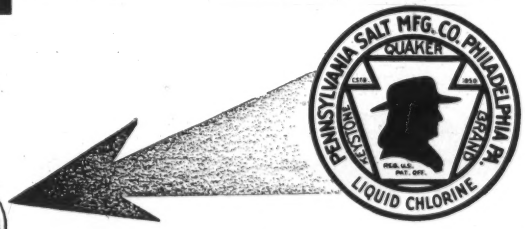


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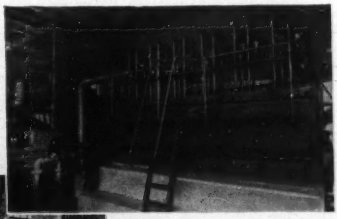
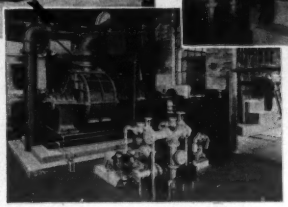


535-hp. Gas Engine direct-connected to Roots-Connersville Blower. This unit is used to aerate sludge.



Blower Room . . . Roots-Connersville Blower. The driving engine can be seen in adjoining room.

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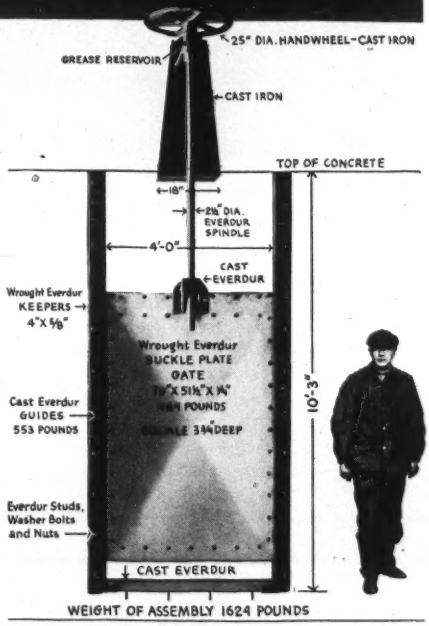


One of the five shut-off gates ready for installation in Rahway Valley Sewage Treatment Works. Designed and built by Row Engineers, Inc., N. Y. Total weight of unit, including cast-iron stand, bearings and handwheel, is 1624 pounds.

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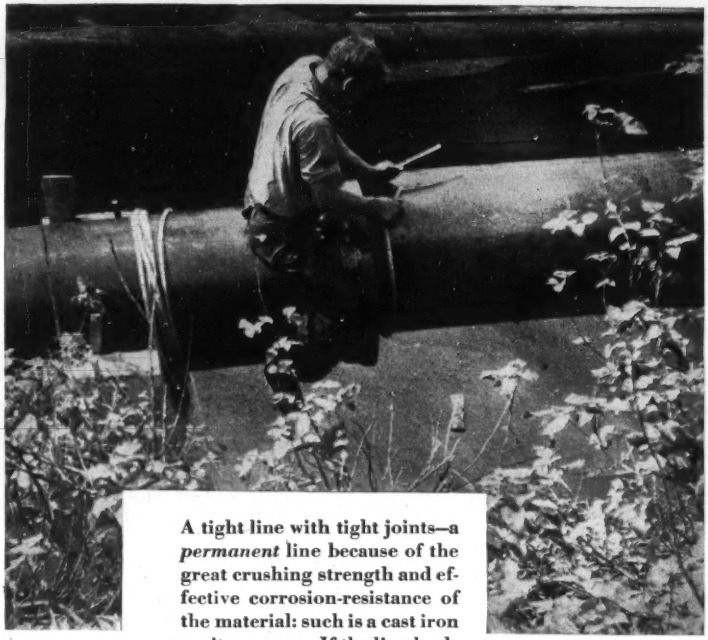

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# Sewage Research

## OBSERVATIONS ON THE DIGESTION OF A SEWAGE SLUDGE OVER A WIDE RANGE OF TEMPERATURES

By Gordon M. Fair and Edward W. Moore

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In a previous paper,* the authors have summarized existing information on the variation of time and rate of sludge digestion with temperature. In this connection they noted the lack of information on the behavior of a single sample of sludge in a wide range of temperatures. To supply this need, they have since then digested single samples of sludge at temperatures of 59, 68, 77, 86, 95, 104, 113, 122 and 140° F. It is the purpose of this paper to present the information obtained.

*Experiments and Results.*—Before a definitive, or master, experiment could be started it was necessary to produce sufficient quantities of well-digested sludge for seeding purposes, *i.e.*, sludge digested at the temperatures to be employed in the master tests. This was accomplished in a preparatory series of digestions. Since two small batches of sludge digested at 68° F. and 122° F. respectively were available, the fresh sludge employed in the preparatory series was seeded with sludge from these two batches. Samples digested below 100° F. could be seeded in a ratio of 1 : 9 on a volatile-matter basis with material previously digested at 68° F. and samples digested above 100° F. on the same basis in a ratio of 1 : 21 with material previously digested at 122° F. The fresh sludge was collected from the Imhoff tanks at Fitchburg, Mass., and contained 6.51 per cent of solids and 60.8 per cent of volatile matter on a dry basis. That the conditions of seeding were unsatisfactory, although the best available, is shown by the length of time required to digest the samples included in the preparatory series and by the lack of agreement between results (Table I).

Table I.—*Time Required to Digest Poorly-Seeded Sludge at Various Temperatures—Preparatory Series*

| Temperature ° F. | Time of Digestion Days |
|---|---|
| 59 | 282 |
| 68 | 115 |
| 77 | 44 |
| 86 | 47 |
| 95 | 36 |
| 104 | 38 |
| 113 | 64 |
| 122 | 99 |
| 140 | 80 |

* *This Journal*, 6, 3 (1934).

The "time of digestion" recorded in Table I was determined, for reasons previously discussed by the authors,* as the number of days necessary to reach 90 per cent of the apparent ultimate gas production of the sludge digested at the lowest temperature, *i.e.*, 59° F. This base value was 448 liters of gas per kilogram of fresh volatile matter.

An attempt was made to include a temperature of 45° F. in the preparatory series. Digestion at this temperature proceeded so slowly, however, that a reliable determination of digestion time had to be considered impossible. After digesting for almost three years, the sample appeared to be still producing gas at much the same slow rate as in the early part of the experiment.

The sludge digested in the master series was also collected at Fitchburg. It contained 2.68 per cent of solids and 74.9 per cent of volatile matter on a dry basis. After thorough comminution, the fresh solids were added in ratios of 2.1 : 1, on a volatile-matter basis, to the seeding residues obtained in the preparatory series and digested at the corresponding temperatures. The results obtained are summarized in Table II.

TABLE II.—*Time Required to Digest Well-Seeded Sludge at Various Temperatures—Master Series*

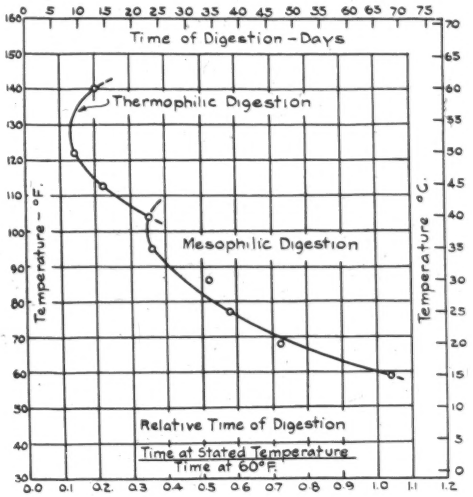
| Temperature ° F. | Time of Digestion, Days | Relative Times (Time at 60° F. = Unity) |
|---|---|---|
| 59 | 67.8 | 1.04 |
| 68 | 46.6 | 0.72 |
| 77 | 37.5 | 0.58 |
| 86 | 33.3 | 0.52 |
| 95 | 23.7 | 0.36 |
| 104 | 22.7 | 0.35 |
| 113 | 14.4 | 0.22 |
| 122 | 8.9 | 0.14 |
| 140 | 12.6 | 0.20 |

The "time of digestion" was determined as for the preparatory series; the basic yield (90 per cent) of gas at 59° F. being 477.5 liters per kilogram of fresh volatile matter. In calculating "relative times," a temperature of 60° F. was chosen as the reference temperature.

The data presented in Table II are plotted in the accompanying diagram. They yield curves similar in their essential features to those included in the authors' earlier publication,* though somewhat different in magnitudes. There is the same evident separation into two zones, mesophilic and thermophilic, each possessing its own optimum. The mesophilic optimum lies between 95 and 105° F., practically at blood heat. This is somewhat higher than indicated by previous tests. The minimum time required for mesophilic digestion is about one-third of the time at 60° F. The thermophilic optimum approaches 125 to 130° F., which is somewhat lower than previously indicated. It has a value about one-eighth that at 60° F. or less than one-half that at the

* *Loc. cit.*

mesophilic optimum. The time of digestion is given at about 22 days for the mesophilic optimum and at about 8 days for the thermophilic optimum. These values are about normal for the type of sludge digested.




Relative time required to digest well-seeded fresh sludge at different temperatures.

*Summary and Conclusions.*—The digestion of a single sludge, adequately seeded, has been observed over a wide range of temperatures. The results obtained show a distinct differentiation between thermophilic and mesophilic digestion. Optimum temperatures of about 128 and 98° F. are indicated for thermophilic and mesophilic digestion respectively. At these temperatures the time of digestion is reduced respectively to one-third and one-eighth the time required at 60° F. The importance of proper seeding is demonstrated.

# THE ELUTRIATION OF DIGESTED SLUDGE

By C. E. Keefer and Herman Kratz, Jr.

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An extensive group of experiments has been conducted in the laboratory [1, 2, 3, 4] and the field [5, 6] at the Baltimore sewage works on the filtration of elutriated sludge. The elutriation process consists of mixing sludge and water, followed by sedimentation of the sludge. The sludge is then withdrawn from the settling tank, and is ready to be coagulated and filtered. The purpose of the process is to reduce the quantity of chemicals needed to flocculate the sludge before filtration. Digested sludge contains ammoniacal compounds, which react chemically with ferric chloride and similar coagulants. By mixing sludge and water some of these compounds diffuse into the water, and their concentration is reduced, the reduction being greater with increasing volumes of water.

In all of the previous experiments at the Baltimore sewage works with the elutriation process, the fill-and-draw method of settling the sludge was used, which consisted of mixing the sludge and the water, followed by settling and withdrawing the sludge. Although this procedure was satisfactory during the early experimental work, it was recognized that the flow of sludge and elutriating water through a sedimentation tank should preferably be continuous when working on a plant scale. Except for some laboratory tests made in 5-gal. bottles, little was known as to the most desirable sedimentation period and no data were available to indicate how well the sludge would settle in a continuous-flow tank and what the concentration of the solids in the sludge would be. In order to obtain information regarding some of these questions, a group of field tests was made using a small steel tank, provided with rotary sludge removal equipment for withdrawing the sludge continuously. The results of this work showed that there was little advantage in using a sedimentation period of 8 hr. as compared with 4 hr. In fact good results were obtained when settling for 2 hr. As has been previously indicated,[5] there was a decided reduction of amino-ammonia nitrogen compounds when one volume of sludge was elutriated with two volumes of water. With increasing quantities of elutriating water there was a greater reduction in the concentration of these compounds, but not in proportion to the amount of water used.

## Equipment Used

Sludge, which had been digested at approximately 85° F., was used throughout the experiment, and was elutriated with clean water. The water flowed through a meter into a mixing trough 21 by 4 in. in plan and 4 in. deep. At intervals of a few seconds a known quantity of sludge was poured into the inlet end of the trough. A porous tube,

through which air was blown, was provided in the bottom of the trough for mixing the sludge and the water. Tests indicated the desirability of agitating the sludge as little as possible to prevent dispersing colloidal materials and producing a poor effluent. The mixture then flowed into the settling tank shown in Fig. 1.

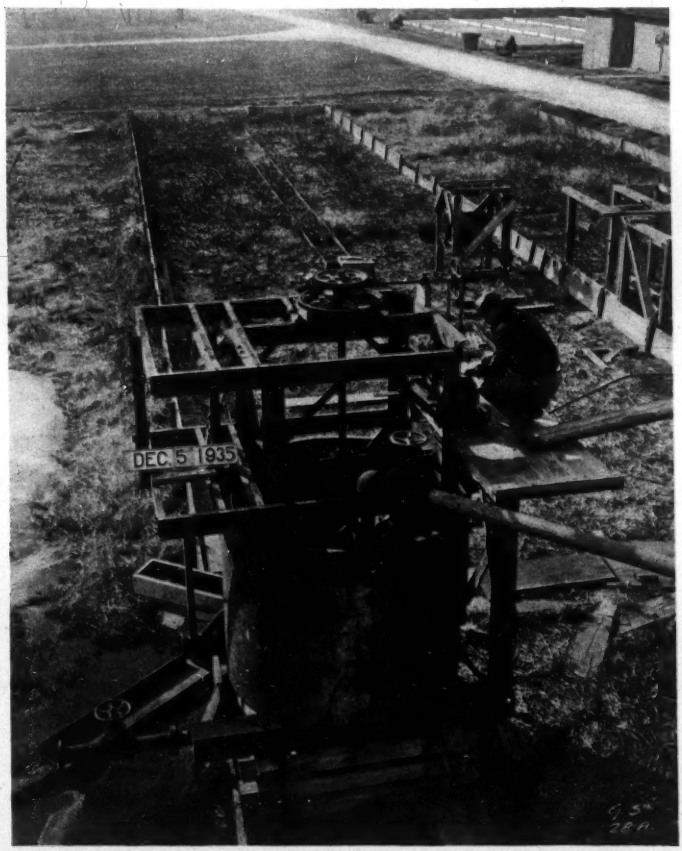


FIG. 1.—Mechanically cleaned tank for settling mixtures of sludge and water.

This tank was of steel construction with a diameter of 6 ft. and a working depth of 4 ft. 4 in. The influent entered the tank near the periphery at the top. The effluent flowed over three circular-shaped weirs, each of which was 4 in. inside of the wall of the tank and 33 in.

long. These weirs were on the opposite side of the tank from the influent pipe. Along the vertical center line of the tank was a steel shaft, to the bottom of which was fastened a spiral-shaped scraper, 5 in. high. As the scraper rotated, the settled sludge was squeegeed to the center and removed through a 4-in. discharge pipe. The upper end of the vertical shaft was fitted with reduction gears, and was driven by an electric motor. The squeegee made one revolution in 2 minutes and 40 seconds.

## Results

Considerable preliminary work was done in order to become familiar with the best routine to follow in conducting the tests. The experiment proper was begun July 16, 1936, and completed October 1, 1936. The sludge was elutriated with 2, 4 and 8 volumes of water.

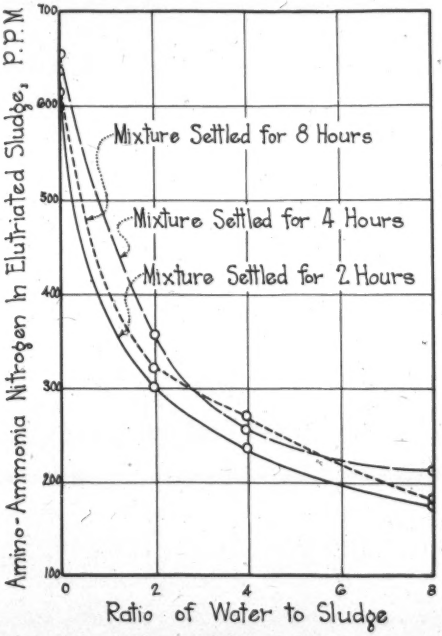


Fig. 2.—Reduction in amino-ammonia nitrogen when digested sludge is elutriated with various volumes of water.

The flow to the settling tank was regulated so that the theoretical detention periods were 2, 4 and 8 hr. As is to be expected in all settling tanks, the actual detention periods were undoubtedly less than the computed values.

Samples of the unelutriated sludge were obtained every 15 minutes. Samples of the settling tank effluent and of the elutriated sludge were collected every 10 minutes. Sampling, however, was not begun until a period had elapsed following the time when influent was admitted into the tank equal to the theoretical detention period in the tank. This procedure was followed in order to be reasonably sure that all of the liquor in the tank prior to beginning the tests would be displaced.

As indicated by the volatile matter in the unelutriated sludge (see Table I), all of the material was well digested. The amino-ammonia nitrogen varied from 500 to 760 p.p.m. As shown in Fig. 2, most of the amino-ammonia nitrogen was removed when the sludge was elu-

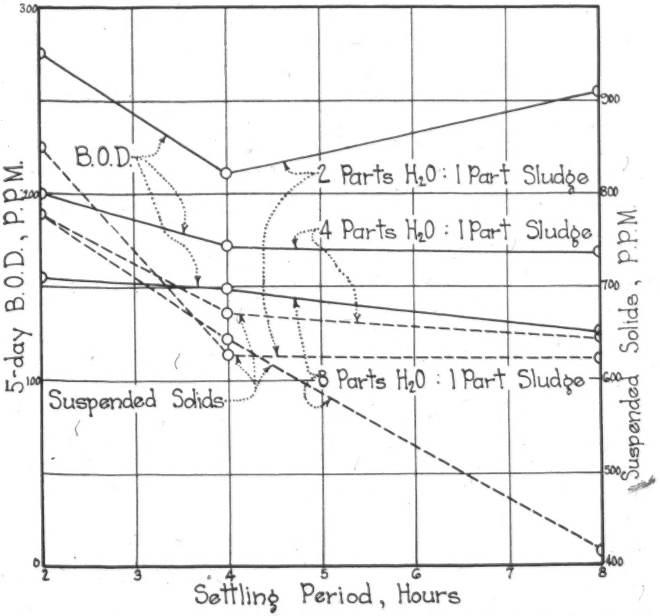
B.O.D.
2 Parts $H_2O$ : 1 Part Sludge
4 Parts $H_2O$ : 1 Part Sludge
8 Parts $H_2O$ : 1 Part Sludge
Suspended Solids
5-day B.O.D., P.P.M.
Suspended Solids, P.P.M.
Settling Period, Hours

FIG. 3.—B.O.D. and suspended solids in elutriate from digested sludge elutriated with various volumes of water.

triated with 2 volumes of water. By using 4 and 8 volumes of water somewhat greater percentages were removed.

The concentration of solids in the sludge before and after elutriation is of interest. Before elutriation the material contained an average of 7.9 per cent of solids and after elutriation 8.6 per cent. This thickening of the sludge was undoubtedly caused by the rotary movement of the sludge squeegee mechanism.

The character of the effluents after settling for 2, 4 and 8 hr. is shown in Table I and Fig. 3. With one exception the effluent improved as

TABLE I.—*Results of Operating Hardinge Mechanism for Elutriating Digested Sludge*

| Date | Detention Period in Settling Tank, Hrs. | Original Sludge | | | | Elutriated Sludge | | | | Effluent | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Solids, % | Volatile Matter, % | pH | Amino-Ammonia Nitrogen, P.P.M. | Solids, % | Volatile Matter, % | pH | Amino-Ammonia Nitrogen, P.P.M. | B.O.D., 5 Days @ 20 degrees C, P.P.M. | Suspended Solids, P.P.M. | pH | Amino-Ammonia Nitrogen, P.P.M. |
| 1936 | | Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge | | | | | | | | | | | |
| July 16 | 2 | 7.2 | 56.8 | 7.2 | 670 | 7.7 | 57.4 | 7.0 | 300 | 275 | 850 | 7.2 | 210 |
| July 30 | 4 | 7.3 | 54.0 | 7.3 | 760 | 8.6 | 55.3 | 6.9 | 355 | 210 | 625 | 7.3 | 200 |
| Aug. 6 | 8 | 8.7 | 53.5 | 7.3 | 730 | 9.7 | 53.6 | 7.0 | 320 | 255 | 622 | 7.4 | 215 |
| | | Sludge Elutriated with 4 Volumes of Water to 1 Volume of Sludge | | | | | | | | | | | |
| Aug. 21 | 2 | 8.0 | 52.9 | 7.3 | 705 | 8.2 | 54.2 | 7.1 | 235 | 200 | 778 | 7.3 | 125 |
| Sept. 4 | 4 | 7.7 | 52.5 | 7.3 | 625 | 8.9 | 53.2 | 7.0 | 255 | 172 | 671 | 7.6 | 89 |
| Sept. 17 | 8 | 8.3 | 51.7 | 7.3 | 500 | 9.6 | 52.4 | 6.9 | 265 | 168 | 645 | 7.5 | 78 |
| | | Sludge Elutriated with 8 Volumes of Water to 1 Volume of Sludge | | | | | | | | | | | |
| Sept. 24 | 2 | 7.8 | 50.7 | 7.5 | 580 | 8.0 | 53.0 | 7.1 | 175 | 154 | 779 | 7.6 | 50 |
| Oct. 1 | 4 | 7.6 | 50.6 | 7.3 | 515 | 9.2 | 52.2 | 6.9 | 210 | 148 | 642 | 7.6 | 49 |
| Sept. 28 | 8 | 8.5 | 50.8 | 7.4 | 600 | 7.2 | 53.4 | 7.0 | 180 | 126 | 414 | 7.5 | 54 |

the sedimentation period was increased. Furthermore, increasing the amount of elutriating water gave an effluent with a lower biochemical oxygen demand. When four volumes of elutriating water were used to one of sludge, the 5-day B.O.D. values of the effluents were 200, 172 and 168 p.p.m. after 2, 4 and 8 hr. sedimentation. The effluent contained 778 p.p.m. suspended solids after 2 hr. settling, 671 p.p.m. after 4 hr. and 645 p.p.m. after 8 hr. It is interesting to note that the 5-day B.O.D. of all the effluents averaged 190 p.p.m., which is less than that of Baltimore raw sewage. The average of the suspended soilds in all effluents amounted to 670 p.p.m.

During the previous sludge elutriation studies in Baltimore [5] the mixture of elutriating water and sludge was settled from 17 to 48 hr. by the fill-and-draw method. The elutriate from a mixture of two volumes of water with one of digested sludge contained an average of 213 p.p.m. 5-day B.O.D. and 332 p.p.m. suspended solids. These figures indicate that an increase in the strength of the effluent may be expected when the continuous-flow method of sedimentation is used. In the light of the work that has been done to date on the elutriation process it has been decided to design the elutriation tanks at Baltimore with a detention period of 4 hr.

## Conclusions

It is appreciated that the tests were conducted with the use of a settling tank that was quite small. It is hoped, therefore, that similar investigations can be continued on a larger scale. The work done to date seems to indicate that there would be little advantage in providing settling tanks with a theoretical detention period of more than 4 hr.

The sewage works is under the general supervision of B. L. Crozier, chief engineer, Department of Public Works, and G. E. Finck, sewerage engineer, with G. K. Armeling, superintendent. Acknowledgments are due the Hardinge Co., who furnished the settling tank. J. W. Bushman, junior chemist, assisted in the laboratory and field work.

## References

1. A. L. Genter, "Adsorption and Flocculation as Applied to Sewage Sludge," *This Journal*, **6**, 689 (1934).
2. A. L. Genter, "Deammonization of Sewage Sludges," *Ind. and Eng. Chem.*, **27**, 218 (1935).
3. C. E. Keefer and Herman Kratz, Jr., "Sludge-Elutriation Tests Establish Cost Figures," *Eng. News-Recd.*, **114**, 289 (1935).
4. A. L. Genter, "Developments in Counter-Current Elutriation of Sludge," *Municipal Sanitation*, **7**, 196 (1936).
5. C. E. Keefer and Herman Kratz, Jr., "The Vacuum Filtration of Elutriated Sludge," *This Journal*, **6**, 845 (1934).
6. C. E. Keefer and Herman Kratz, Jr., "Vacuum Filtration of Sludge from Secondary Settling Tanks," *This Journal*, **7**, 963 (1935).

# THE OXYGEN DEMAND OF MIXTURES OF ACTIVATED SLUDGE AND SEWAGE

By Edward W. Moore

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The rate at which oxygen is consumed by the aerobic decomposition of the organic matter contained in sewage has for many years received the attention of workers in the field of sewage disposal. The rate at which diluted sewage takes up oxygen has been thoroughly investigated by Phelps, Theriault, and many others. The increasing use of the activated sludge process has drawn attention to the rate of oxygen consumption of mixtures of sewage and sludge. Among those who have contributed to our knowledge of this subject are Theriault and MacNamee,[1, 2] Grant, Hurwitz and Mohlman,[3] and Kessler and Nichols.[4] These workers have shown that mixtures of sewage and aerobic sludges consume oxygen far more rapidly than does sewage alone. Theriault and MacNamee have also found that the rate of consumption, like the rate of biochemical oxygen demand of sewage, can be expressed in terms of the reaction velocity constant. According to Theriault and MacNamee, the rate of oxygen consumption of mixtures of sewage and sludge is fifteen to twenty times as great as the rate of consumption of sewage alone. In analyzing the data presented by Kessler and Nichols, the author has reached certain conclusions which he believes to be of interest in relation to the work of Theriault and MacNamee. These are offered in the hope that they may be of some value in the development of activated sludge theory.

## Mathematical Considerations

In the September, 1935, issue of This Journal, Kessler and Nichols have presented the results of a series of experiments on the rate of oxygen consumption of mixtures of sewage and activated sludge. The rates of oxygen consumption over short intervals of time were determined, by an ingenious technique, on mixtures of activated sludge and sewage which had been aerated for periods ranging up to seventy-two hours. In expressing their results, Kessler and Nichols introduced a new term, the Nordell Number, which they defined as the rate of oxygen utilization of the mixture in p.p.m. per hour. They also developed an empirical formula expressing the change of the Nordell Number with time. The practical value of the Nordell Number was demonstrated by Kessler and Nichols; the author wishes to consider its theoretical significance. Those familiar with the differential form of the equation of biochemical oxygen demand, $dX_t/dt = 2.3kL_t$, will recognize the Nordell Number as an approximation, $\Delta X_t/\Delta t$, of the instantaneous rate of oxygen consumption at any time $t$, namely $dX_t/dt$. Here $X_t$ is the amount of oxygen consumed in time $t$, and $L_t$ is the demand still unsatisfied. It should therefore be possible to treat the Nordell Number in much the same way as B.O.D. results, and to

obtain from it valuable information on the processes going on in mixtures of sewage and activated sludge.

The more familiar form of the equation of biochemical oxygen demand is $L_t = L \cdot 10^{-kt}$, where $L$ is the total first-stage biochemical oxygen demand of the sewage, and $k$ is the velocity constant of the process. The fundamental form, however, is the differential, which may be expressed as follows:

$$* \frac{dX_t}{dt} = 2.3kL10^{-kt}.$$

$$L_t = L - X_t = L \cdot 10^{-kt} = Le^{-2.3kt}$$

Differentiating, $\frac{d(L - X_t)}{dt} = -\frac{dX_t}{dt} = -2.3kLe^{-2.3kt}$ or $\frac{dX_t}{dt} = 2.3kL\ 10^{-kt}$.

Taking the logarithm of both sides of this equation, we obtain

$$\log \frac{dX_t}{dt} = -kt + \log 2.3kL.$$

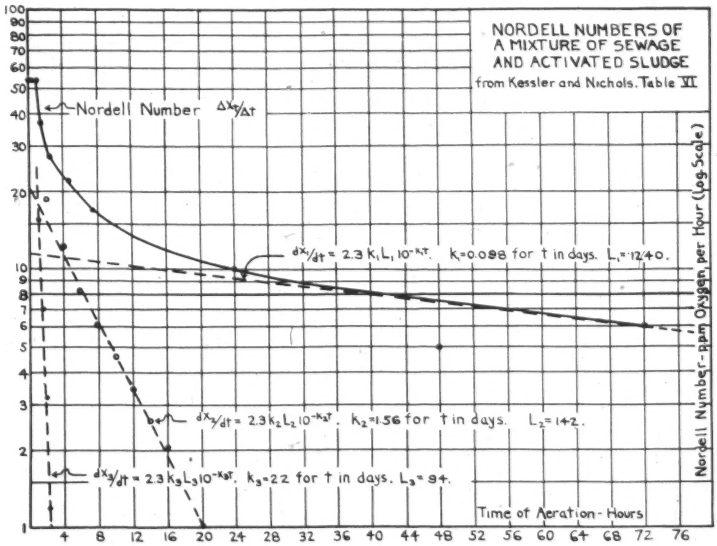
It is therefore apparent that if the logarithm of the rate, $dX_t/dt$, of oxygen consumption at any time $t$, is plotted against time, a straight line will be obtained. The slope of this line will be equal to $-k$, and the intercept at zero time will be $2.3kL$. It is thus possible to determine the characteristics of a biochemical oxygen demand curve from a knowledge of the instantaneous rates of oxygen consumption at definite time intervals.

## Method of Analysis

If the Nordell Numbers of Kessler and Nichols are taken as approximately equal to the instantaneous rates of oxygen consumption at the time of measurement, and their logarithms are plotted against the length of time the mixtures have been aerated, smooth curves of constantly decreasing negative slope are obtained, except for the first parts of their experiments, in which the Nordell Numbers are constant. Obviously, then, the results obtained by Kessler and Nichols cannot be expressed by means of the simple biochemical oxygen demand equation. If, however, these curves are extended far enough in time, they show a marked tendency to approach as an asymptote a straight line having a negative slope of about 0.1. The value of the rate constant, $k$, for the oxidation of sewage or polluted water is generally accepted as 0.1 at 20° C.[5] Other oxidation processes possessing higher $k$ values, and consequently going to completion in shorter times, would, if superimposed on this primary oxidation process, produce substantially the type of curve observed when the logarithms of the Nordell Numbers are plotted against time,—that is, a curve of decreasing negative slope approaching asymptotically a straight line having a negative slope of 0.1. It is possible by graphical methods to determine the characteristics of these hypothetical oxidation processes from the Nordell Number curves.

* This form may be obtained from the common one by the following mathematical steps.

In the accompanying figure, the set of results given in Table VI of Kessler and Nichols' paper is plotted as previously indicated, and the graphical method used to analyze these results is illustrated. The graphical analysis consists essentially of three steps. The asymptotic straight line is first drawn. This represents the equation $dX_1/dt = 2.3k_1L_1 10^{-k_1 t}$. For this particular case it is found that $k_1 = 0.098$ (time in days) and $L_1 = 1240$ p.p.m. of oxygen demand. The difference between the ordinate of this straight line and the ordinate of the Nordell Number curve is then determined at suitable time intervals, and plotted on the same graph. It is found that these differences, with the exception of those calculated for the first two or three hours of aeration, are well represented by a second straight line. This line corresponds to the equation $dX_2/dt = 2.3k_2L_2 10^{-k_2 t}$ and in this case the value of $k_2$ is 1.56 and that of $L_2$ is 142 p.p.m.


NORDELL NUMBERS OF A MIXTURE OF SEWAGE AND ACTIVATED SLUDGE
from Kessler and Nichols. Table VI
Nordell Number $\Delta X_2/\Delta t$
$dX_1/dt = 2.3\,K_1L_1\,10^{-K_1T}$. $K_1$=0.098 for t in days. $L_1$=1240.
$dX_2/dt = 2.3\,K_2L_2\,10^{-K_2T}$. $K_2$=1.56 for t in days. $L_2$=142.
$dX_3/dt = 2.3\,K_3L_3\,10^{-K_3T}$. $K_3$=.22 for t in days. $L_3$=94.
Nordell Number-ppm Oxygen per Hour (Log Scale)
Time of Aeration-Hours
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76

After the first two or three hours of aeration, the sum of $dX_1/dt$ and $dX_2/dt$ is in all cases substantially equal to the observed Nordell Number. During this first period, however, the observed Nordell Number changes rapidly, and is always greater than the sum of $dX_1/dt$ and $dX_2/dt$. A third difference may therefore be obtained by subtracting this sum from the observed Nordell Number. Excluding the short initial period during which the Nordell Number remains constant, these differences can apparently be plotted as a third straight line. However, the small number of points available makes the validity of the straight line representation

less obvious than in the preceding step. The equation of the third line is then $dX_3/dt = 2.3k_3L_3 10^{-k_3 t}$. The value of $k_3$ is 22, and that of $L_3$ is 94 p.p.m.

We have thus broken down the Nordell Number-time equation into three equations of the type used to represent biochemical oxygen demand:

$$N = \frac{dX}{dt} = 2.3k_1L_1 10^{-k_1 t} + 2.3k_2L_2 10^{-k_2 t} + 2.3k_3L_3 10^{-k_3 t}.$$

The methods used in arriving at this equation are similar to those used by Theriault and MacNamee [1] in their study of the oxidation of mixtures of channel sludges, and by Streeter [6] in his study of bacterial changes in polluted water.

Table I shows a comparison of the values of $N$ computed from this

TABLE I.—*Nordell Numbers of a Mixture of Sewage and Activated Sludge*

| Time Aerated Hours | Nordell Number from Kessler & Nichols | | $\frac{dX_1}{dt}$ | $\frac{dX_2}{dt}$ | $\frac{dX_3}{dt}$ | Sum |
|---|---|---|---|---|---|---|
| | Computed | Observed | | | | |
| 0.00 | — | — | 11.6 | 21.3 | 202.0 | 234.9 |
| 0.08 | 54 | 54 | 11.6 | 21.0 | 169.0 | 201.6 |
| 0.5 | 54 | 54 | 11.5 | 19.8 | 69.0 | 100.3 |
| 1.0 | 54 | 54 | 11.5 | 18.3 | 23.6 | 53.4 |
| 1.5 | 36.7 | 37 | 11.4 | 17.0 | 8.9 | 37.3 |
| 2.0 | 29.9 | 30 | 11.4 | 15.8 | 2.8 | 30.0 |
| 2.5 | 26.5 | 27 | 11.3 | 14.6 | 1.0 | 26.9 |
| 4.63 | 20.0 | 22 | 11.1 | 10.6 | — | 21.7 |
| 7.5 | 16.3 | 17 | 10.8 | 6.9 | — | 17.7 |
| (15) | (12.2) | — | 10.0 | 2.2 | — | 12.2 |
| 24 | 10.0 | 10 | 9.3 | 0.6 | — | 9.9 |
| (36) | (8.5) | — | 8.3 | 0.1 | — | 8.4 |
| 48 | 7.4 | 5 | 7.3 | — | — | 7.3 |
| (60) | (6.7) | — | 6.6 | — | — | 6.6 |
| 72 | 6.2 | 6 | 5.9 | — | — | 5.9 |

equation using the constants given before, those computed by the equation of Kessler and Nichols, and those actually determined in the particular experiment under consideration. It will be noted that the results obtained by the use of the three-rate formula agree closely with the Nordell Number as computed and determined by Kessler and Nichols, except in the case of the Nordell Numbers obtained during the first hour of aeration. Discussion of possible reasons for the discrepancies observed during this period is reserved for a later section of the paper.

## RESULTS OF ANALYSIS

If the three equations which are summed up to yield the Nordell Number represent three distinct types of oxygen consuming processes going on simultaneously in a mixture of sewage and activated sludge, then the values of the three rate constants should be in reasonable agreement

for all of the data. We expect the rate constant for oxidation of sewage alone at 20° C. to be close to 0.1, and to change but little for temperatures a few degrees above or below 20°. If $k_2$ and $k_3$ are rate constants of actual chemical or biochemical processes, we must expect them to show a comparable degree of consistency in all experiments. Since temperatures are not given in Kessler and Nichols' paper, it will be necessary to assume that all experiments were made at approximately the same temperature.

The author has applied his method of analysis to a number of the experiments for which data are given in Kessler and Nichols' paper, avoiding only those for which excessive extrapolation would be required in order to render the method applicable. The constants so obtained are given in Table II. The work of Theriault and MacNamee on mixtures of

TABLE II.—*Values of Constants Obtained*

| Experiment | $k_1$ | $L_1$ | $k_2$ | $L_2$ | $k_3$ | $L_3$ |
|---|---|---|---|---|---|---|
| Kessler and Nichols [4] | | | | | | |
| Laboratory Tank-Raw Sewage | 0.098 | 1240 | 1.56 | 142 | 22 | 94 |
| Laboratory Tank-Diluted Sewage | 0.100 | 990 | 1.52 | 123 | 21 | 22 |
| Newark, N. Y., Dec. 30, 1934 | 0.090 | 500 | 1.35 | 49 | 15 | 26 |
| Newark, N. Y., Dec. 31, 1934 | 0.080 | 820 | 1.32 | 104 | 21 | 33 |
| Newark, N. Y., Jan. 1, 1935 | 0.091 | 598 | 1.43 | 66 | 10 | 15 |
| Milwaukee, Nov. 8, 1934 | 0.092 | 1134 | 1.24 | 118 | 8 | 32 |
| Milwaukee, Nov. 18, 1934 | 0.089 | 368 | 1.44 | 38 | 20 | 13 |
| Milwaukee, Dec. 1, 1934 | 0.090 | 1270 | 1.20 | 141 | 12 | 55 |
| Madison, Wis., Mar. 9, 1935 | 0.104 | 838 | 3.06 | 58 | 11 | 19 |
| Theriault and MacNamee [1] | | | | | | |
| 18–22° C | 0.08 | 1088 | 1.6 | 190 | — | — |
| 26–32° C | 0.18 | 1179 | 2.0 | 368 | — | — |
| Stored Sludge, 20° C | 0.06 | 1216 | 1.5 | 391 | — | — |
| MacNamee [2] | $k = 2.0$ | | | | | |

*Note:* $k$ values are for time in days, values of $L$ in mg. per liter of mixture.

sewage and channel sludges is also included in the table. It is evident from the results that $k_1$ and $k_2$ show a degree of consistency commensurable with that usually found in biological work. The values of the third rate constant $k_3$ are less consistent, and its position as a fundamental constant is less clearly indicated. It should be noted, however, that several factors make the exact determination of the value of $k_3$ difficult. Its evaluation rests on a few Nordell Number determinations made in the early stages of the experiment. Here the Nordell Numbers are high, and the assumption that they are equal to the instantaneous rate of consumption, $dX_t/dt$, is seriously in error, since the time required to determine the Nordell Number is an appreciable fraction of the time the mixtures have been aerated. In other words, the Nordell Numbers are really equal to

$\Delta X_t/\Delta t$, where $\Delta t$ is a significantly large time interval when the Nordell Numbers are changing rapidly with time. Another source of error lies in the graphical method employed. Errors made in determining $k_1$ and $k_2$ are thrown forward into the determination of $k_3$. It is therefore possible that $k_3$ has a real significance, despite the observed variation in its value.

The first rate constant, $k_1$, corresponds very closely in its numerical value to the rate constant commonly accepted for biological oxidation of sewage and polluted water [5] at temperatures in the vicinity of 20° C. The values 0.08 to 0.10 are typical for this process. It is reasonable to assume that oxidation of this type goes on at all times in mixtures of activated sludge and sewage, but that it is usually overshadowed by other more rapid types of oxidation processes characteristic of these mixtures.

The second rate constant, $k_2$, shows values ranging from 1.2 to 1.6, excluding one exceptionally high value. It thus represents an oxygen consuming process which is twelve to twenty times as fast as the normal rate of oxidation for sewage, referred to in the previous paragraph. Theriault and MacNamee [1] in investigating the oxygen demand of mixtures of sewage and channel sludges, found evidence of the existence of such a process, and deduced that its rate constant had a value of 1.6 at 18–22° C. MacNamee [2] in a later paper finds a rate constant of 2.0 in mixtures of sewage and activated sludge, using a somewhat different method of approach to the problem. MacNamee's paper seems to suggest that this constant represents a process of rapid oxidation of some of the organic matter present in the sludge liquor. The author offers for consideration the idea that this process corresponds to the rapid oxidation of a portion of the organic matter which has been adsorbed from the sewage by the activated sludge floc. It is known that adsorbed substances often show a high degree of reactivity. It is further suggested that this oxidation is necessary for the regeneration of the activated sludge, since regeneration consists mainly of returning the activated sludge flocs to a condition in which their surfaces are again capable of adsorbing the organic matter in sewage. It may be that this condition can be reached by partial oxidation of the layers of organic matter picked up by the sludge flocs.

A reaction with a velocity constant of 1.5 is 60 per cent complete in 6 hours, and 90 per cent complete in 16 hours. In American activated sludge plants, a 6-hour period of aeration of the mixture of sewage and sludge is common, and relatively large percentages of sludge are recirculated. In some British plants it has been the custom to aerate the returned sludge alone for periods up to 18 hours, and to recirculate smaller percentages of sludge. Obviously, when smaller percentages of returned sludge are used, it is necessary to regenerate them more completely. There is, then, a rough agreement between the time required in practice for regeneration of activated sludge, and the time required for the oxidation process represented by $k_2$ to go to various stages of completion.

The third rate constant, $k_3$, with values ranging from 8 to 22, represents a reaction which is five to fourteen times as fast as the reaction represented by $k_2$. The existence of such a reaction may possibly be regarded as questionable, since the value of the rate constant varies con-

siderably from one experiment to the other, and since other workers have never reported it. However, if the validity of the first two steps in the analysis is assumed by reason of their substantial agreement with the results of other workers, it is necessary to postulate a third oxygen consuming process of very high velocity to account for the high rates of oxygen consumption which Kessler and Nichols observed in mixtures of sewage and activated sludge during the first hour or two of aeration. It should also be noted that in the investigation of the oxygen consumption of mixtures of sewage and activated sludge, it would be necessary to work rapidly to find evidence of the existence of a reaction of such high velocity. The technique employed by Kessler and Nichols is particularly well adapted to show the existence of such a reaction, since it measures oxygen consumption over a short period of time. A number of determinations of oxygen consumption may therefore be made in the first two hours of the experiment. The methods used by other workers often have not permitted such close observation of the oxygen demand during the early stages of the experiment. A reaction with a velocity constant of 20 is 90 per cent complete in 1.2 hours, and its observation therefore requires an especially rapid technique.

Speculation as to the probable nature of the oxygen-consuming process or processes represented by $k_3$ is of little value until more information is available. It will therefore be sufficient to mention a few processes which might cause a rapid absorption of oxygen in mixtures of activated sludge and sewage. It has frequently been assumed that sewages and sludges may, under certain conditions, contain substances capable of reacting directly with oxygen. Such substances would, of course, have a high rate of oxygen demand. If the sludge floc were lower in oxygen content than the surrounding liquid, oxygen would diffuse from the liquid into the floc. The apparent rate of oxygen consumption would be rapid, but the total demand exerted by this process could not be as great as the observed values of $L_3$. Another possibility is the direct adsorption of oxygen by the sludge floc. The rate constant $k_3$ may represent one of these processes, or a combination of them, or it may represent some process as yet unrecognized.

## The Initial Period of Constant Oxygen Absorption

In all the studies reported by Kessler and Nichols the Nordell Number remained constant for a short time after the beginning of the experiment. Grant, Hurwitz, and Mohlman also found that the rate at which mixtures of sewage and activated sludge absorbed oxygen remained substantially constant for an even longer time interval than that observed by Kessler and Nichols. The ideas so far developed in this paper do not take into account this period of constant rate of oxygen absorption. Theoretically the rate of oxygen consumption should be highest at the beginning of the experiment, and should decrease steadily as time increases. However, there is a physical limit to the rate at which oxygen can be taken out of the liquor by the activated sludge. The floc must constantly be brought into contact with fresh liquor from which the dissolved oxygen has not

been removed. With this in mind, it is not unreasonable to expect that at times the controlling factor in oxygen absorption will be not the rate at which the floc can take up oxygen, but the rate at which oxygen can be brought to the floc. In any given experiment the latter rate may be substantially constant. The results obtained by Grant, Hurwitz and Mohlman can be successfully reconciled with this idea. They found that an increase in the quantity of sludge in sewage increased the total rate of oxygen absorption, but decreased the rate of absorption per unit of sludge present. In other words, oxygen could be fed to any individual sludge particle more rapidly in a thinner mixture than in a thicker one. It may be, therefore, that the initial constancy of the rate of oxygen absorption can be accounted for as a limiting rate controlled by physical factors. It should also be noted that Kessler and Nichols refer to certain experiments in which they obtained very high Nordell Numbers with very short periods of shaking of their mixtures of sewage and sludge. They eliminated these high results by allowing the initial demand to be satisfied before determining the Nordell Number of the mixture. It is possible that this procedure had some part in producing an initially constant Nordell Number.

## The Total Oxygen Demand

Each of the three oxygen consuming processes or reactions into which the Nordell Number curves have been analyzed has a definite total oxygen demand. The method of computation of this demand has already been indicated, and the demands for the three processes have been designated by the letters $L_1$, $L_2$ and $L_3$. The values of these quantities and their sums are set forth in Table III, together with whatever information could be obtained on the actual B.O.D.'s of the sewages and sewage-sludge mixtures,

Table III.—*Total Oxygen Demands and Other Data, Derived from Kessler and Nichols' Experiments.*

| Experiment | Calculated B.O.D. | | | | Observed B.O.D. of Sewage | | Observed B.O.D. of Mixture | | Suspended Solids | Volatile Suspended Solids |
|---|---|---|---|---|---|---|---|---|---|---|
| | $L_1$ | $L_2$ | $L_3$ | $\Sigma L$ | 5 day | Ultimate* | 5 day | Ultimate* | | |
| Laboratory— | | | | | | | | | | |
| Raw sewage | 1240 | 142 | 94 | 1476 | 1100 | 1620 | — | — | — | — |
| Diluted sewage | 990 | 123 | 22 | 1135 | 695 | 1020 | — | — | — | — |
| Newark Dec. 30 | 500 | 49 | 26 | 575 | 404 | 595 | 337 | 495 | 950 | — |
| Dec. 31 | 820 | 104 | 33 | 957 | 360 | 530 | 300 | 441 | 2288 | — |
| Jan. 1 | 598 | 66 | 15 | 679 | 260 | 382 | 166 | 244 | 2457 | — |
| Milwaukee Nov. 8 | 1134 | 118 | 32 | 1284 | — | — | 280 | 412 | 3000 | 2340 |
| Nov. 18 | 368 | 38 | 13 | 419 | 120 | 177 | 106 | 156 | 900 | 701 |
| Dec. 1 | 1270 | 141 | 55 | 1466 | 300 | 441 | 201 | 296 | 5600 | 3920 |

* 5 day demand divided by 0.68.

and on the suspended solids in the mixtures. It will be seen that the sum of the values of $L$ for each experiment is greater than the expected B.O.D. of the mixture as computed from the determined B.O.D.'s of the sewage and the sludge liquor. This is to be anticipated in view of the statement made by Grant, Hurwitz and Mohlman that mixtures of sewage and sludge absorbed more oxygen in a few hours of aeration than would be required to satisfy the entire first stage B.O.D. of the sewage used. A large portion of the oxygen consumption is probably due to the organic matter already present in the sludge.

The relationships between the various values of $L_1$, $L_2$, $L_3$ and the determined B.O.D.'s of the sewage and sludge liquor are obscure. The value of $L_2$ is generally 9 to 10 per cent of the sum of $L_1$, $L_2$ and $L_3$. It also appears to be roughly related to the ultimate B.O.D. of the sewage as determined by the dilution method, but does not bear any definite proportionality to it. The value of $L_1$, the long time demand, appears to be more closely tied up with the quantity of suspended solids in the mixture than with anything else. It is considerably greater than $L_2$ and $L_3$. The value of $L_3$ appears to have no relationship to any of the other quantities for which values are available.

## Biological Considerations

It will be noted that oxygen demands have been treated throughout the paper as if they were simple chemical reactions subject to direct velocity measurements. Of course, the oxygen demands are really in large part the results of complex chains of reactions going on in the cells of many types of organisms inhabiting activated sludge. The fact that an oxygen demand can be treated in the same way as a unimolecular chemical reaction implies nothing about the mechanism by which the oxygen demand is exerted, except possibly that in this complex mechanism there is a controlling chemical or physical reaction which may be expressed in terms of the unimolecular law. There is good precedent for the treatment of oxygen demands as chemical reactions with measurable velocities in the familiar equation for the biochemical oxygen demand of sewage and polluted waters. Such treatment has proved its value in the study of biochemical oxygen demand; it may be of similar value in the study of the activated sludge process.

## Summary and Conclusions

The data published by Kessler and Nichols on the rate of oxygen consumption of mixtures of sewage and activated sludge can be represented as the sum of three unimolecular reactions of the same type as that used to represent the biochemical oxygen demand of sewage and polluted waters. The first reaction has a velocity constant whose value closely approaches the value generally accepted for sewage and polluted waters. The second reaction has a velocity constant roughly fifteen times as great as the first. It corresponds closely to a similar reaction previously reported by Theriault and MacNamee in mixtures of channel sludges and sewage. The

third reaction has a very high velocity constant, approximately ten times that of the second, and has not been previously reported in the literature. This method of formulating the oxygen demand of mixtures of sewage and sludge can probably have no direct practical significance, but the author hopes that it may make some contribution to our knowledge of the processes taking place in such mixtures.

The author is indebted to Professor G. M. Fair for his aid in preparing this paper and in developing the ideas expressed therein.

## References

1. Theriault and MacNamee, *Ind. Eng. Chem.*, **22**, 1330 (1930).
2. MacNamee, *This Journal*, **8**, 562 (1936).
3. Grant, Hurwitz and Mohlman, *Ibid.*, **2**, 228 (1930).
4. Kessler and Nichols, *Ibid.*, **7**, 810 (1935).
5. Theriault, *U. S. Public Health Bull.* 173 (1928).
6. Streeter, *This Journal*, **6**, 208 (1934).

# CHEMICAL COAGULATION OF SEWAGE*

## VI. CLARIFYING VALUE OF RETURN SLUDGE

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At as early a date as 1873 the return of sludge to the raw sewage as an aid to clarification in chemical coagulation was recorded. Later British practice often included this procedure. Modern practice of chemical treatment in this country has included plant and pilot plant experimentation along these lines. Despite discussion and use, information as to the actual effect and degree of improvement in clarification afforded by chemical sludge, or the saving in coagulant accomplished is rare and then often indefinite.

Questions such as the effects of sludge produced by different chemicals, the volume of sludge, concentration of sludge, return of sludge before and after coagulant addition on pH changes, return of acid or alkaline sludges, need to be answered before more definite conclusion can be drawn.

The results presented in this paper constitute an entry into an investigation to determine the degree of clarifying activity of chemical sludges, alone and in conjunction with chemicals for adjusting the pH. A study is also made of the effects of certain factors which affect the efficiency of returning sludge under different conditions.

### Procedure

Raw sewage from different sources was treated with chemicals, flocculated 30 minutes and allowed to settle for two hours. Sludge was then drained off and used immediately. Some of the supernatant liquor was used in preparation of the mixtures. The supernatant liquor was eliminated as a factor in clarification by control tests. In the case of coagulants yielding a bulky sludge, 1000 c.c. of raw sewage was used with 500 c.c. of sludge-supernatant liquor mixtures. The concentration of solids was varied by using increasing amounts of sludge, and making up the volume to 500 c.c. with supernatant liquor.

This procedure provided an equal amount of removable suspended material in each jar, with a varied concentration of chemical sludge. With denser sludges, 1350 c.c of sewage was used with 150 c.c. of mixture. Suspended solids were determined on the sludge and sewage and suspended solids or turbidity on the effluents. When coagulants were used in addition to return sludge they were added after the sludge was mixed. Flocculation time was thirty minutes and settling time one hour. All pH measurements were made with a Beckman glass elec-

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

trode, which gave very satisfactory results. Sewages of varying characteristics, as described in the first paper of this series, were used.

*Return of Ferric Iron Sludge.*—To determine the effect of ferric iron sludge, when returned in increasing quantities, sludges were obtained by coagulation with 20 p.p.m. of iron ($FeCl_3$). They contained an average of about 0.6 per cent of solids. Three different types of sewages were used and in each case the results were similar. The average results for all trials are shown in Table I.

TABLE I.—*Clarifying Effect of Increasing Amounts of Return Sludge*

| Suspended Solids Mixed Liq. | 253* | 523 | 812 | 1061 | 1319 | 4631 |
|---|---|---|---|---|---|---|
| No Additional Coagulant | | | | | | |
| Susp. Sol. Eff. | 81 | 55 | 52 | 60 | 59 | 79 |
| Increased Removal Due to Sludge | — | 26 | 29 | 21 | 22 | 2 |
| 5 p.p.m. Fe as ($FeCl_3$) | | | | | | |
| Susp. Sol. Eff. | 49 | 37 | 38 | 39 | 38 | 39 |
| Increased Removal Due to Sludge | — | 12 | 11 | 10 | 11 | 10 |

* No sludge.

Doubling the suspended solids concentration of the raw sewage with chemically coagulated return sludge gave an increased removal of suspended material, both with and without a small dosage of ferric chloride. Further addition of sludge did not increase the removal of suspended solids and excessive quantities in some instances gave poorer clarification than small quantities.

Addition of coagulant to the sewage-sludge mixture decreased the effectiveness of the sludge on the basis of p.p.m. suspended solids removed. This may be caused by removal of the more readily coagulable suspended material by the more active coagulant, leaving only the very fine solids for the return floc to pick up. As these particles are difficult to coagulate even with $FeCl_3$, little removal may be expected by the returned floc. This is well illustrated in Fig. 1, which shows the results when sewage was treated with a constant volume of chemical sludge and varied amounts of $FeCl_3$. With no coagulants, 36 p.p.m. suspended solids were removed by the sludge; when 25 p.p.m. of iron was employed, in addition, only 5 p.p.m. removal could be attributed to the sludge.

It is conceivable that the order of addition of chemical and sludge to the sewage would be of some importance in clarification results. The results presented in Table II, however, indicate that there is no ap-

TABLE II.—*Return of Sludge Before and After Coagulant Addition*
(Sewage 328 p.p.m. suspended solids; 512 p.p.m. return sludge used)

| p.p.m. Fe ($FeCl_3$) | 0 | 2 | 4 | 6 | 8 | 10 | 15 |
|---|---|---|---|---|---|---|---|
| Sludge + Coagulant | 94 | 80 | 67 | 46 | 36 | 33 | 20 |
| Coagulant + Sludge | 94 | 80 | 70 | 48 | 40 | 33 | 30 |

parent difference when the sludge is added before or after ferric chloride. Since the sewage was completely treated to produce this sludge, no large immediate absorption of coagulant would be expected. Apparently the removal of materials from the raw sewage by the $FeCl_3$ prevents reaction which might take place with the returned sewage. The effect of the sludge appears to be entirely physical. The following experiment substantiates these observations.

Three liters of three different sewage samples were treated with 0, 10, 20, and 30 p.p.m. Fe ($FeCl_3$) respectively and settled until the sludge

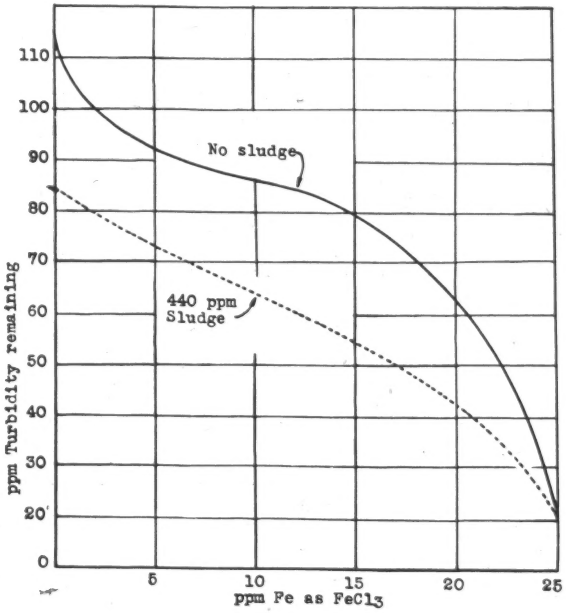


FIG. 1.—Effect of return chemical sludge with varied iron salt dosage ($FeCl_3$ used).

volume was 150 c.c. Ten p.p.m. Fe gave partial coagulation, 20 p.p.m. complete coagulation and 30 p.p.m. was in excess but not sufficient to cause re-dispersion. Each sludge was added to 1350 c.c. of raw sewage and the mixtures were flocculated for 30 minutes and settled one hour. This procedure was repeated, using 6 liters of sewage to obtain a more concentrated sludge. Sludge from the excessive chemical treatment was no more effective than that which was treated to give satisfactory coagulation. Poorer clarification was obtained with the partially treated sludge than with the completely coagulated, but the former was effective to some extent. Doubling the sludge quantity showed no

added clarifying effect. This checks other observations and results given above. It should be remembered that in order to produce twice the concentration of solids in the same volume the amount of coagulant added was double that of the sludge in the lower concentration. A larger amount of spent coagulant present in the sludge had therefore no increased beneficial effect. This is clearly shown in Fig. 2, indicating that the suspended solids remaining in the effluent were practically the same for different coagulant additions, when the suspended solids in the sewage-sludge mixture were increased from 890 to 1780 p.p.m.

*Return of Lime-Iron Sludge.*—In most of the processes where sludge is returned (English practice) chemicals are employed for adjusting the pH. In this country several processes include return of lime-iron

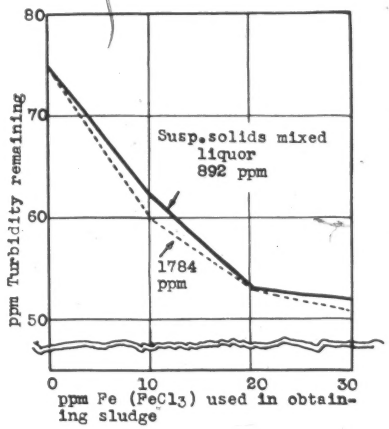


FIG. 2.—Effect of mixed liquor solids concentration on clarification with different amounts of coagulant.

sludge. As lime sludge is of higher pH than the raw sewage, the addition of such sludge to raw sewage might aid in raising the pH value and thus lowering the subsequent lime dosage necessary to obtain best results with the most economical use of coagulant.

The effectiveness of increasing amounts of sludge obtained after treatment with lime to 9.0, plus small amounts of ferric chloride (5 to 10 p.p.m. Fe) and the change in pH subsequent to addition of sludge to the raw sewage, were first studied. Experiments were the same as with the iron sludge, except that as the lime sludges were more compact the volume of sludge returned to the raw sewage was less (150 c.c. maximum). This amount gave concentrations of suspended solids in the mixed liquor of over 2000 p.p.m.

The results obtained with return lime sludge added in increasing amounts to three sewages of varied character, and the accompanying

changes in pH values of the raw sewage, are shown in Fig. 3. Additional pertinent data are shown in Table III. Perusal of the table and curves shows that clarification of stale as well as fresh sewage is affected by the return of lime-iron sludge and that clarification increases gradually with the quantity of sludge added. The pH values in both

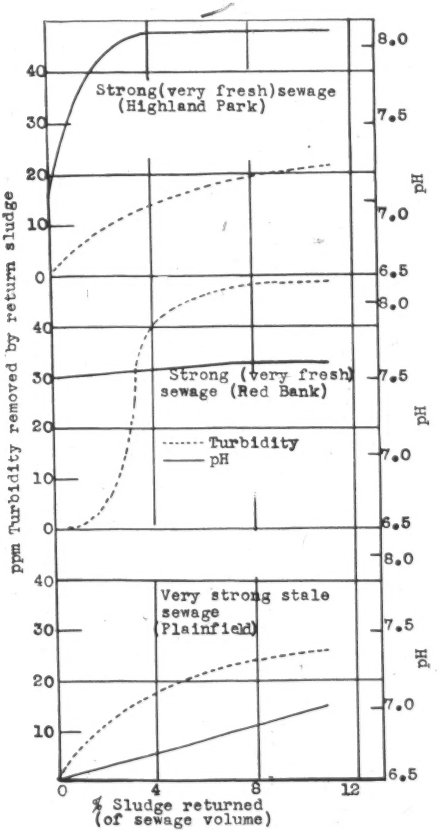


FIG. 3.—Effect of lime-iron sludge on turbidity removal and pH changes.

fresh and stale sewage were also affected but not to the same degree. The changes in pH values caused by the return of lime-ferric iron sludge were variable. With large quantities of return sludge the maximum pH change was 0.9. With the most economical amount of sludge (5.2 per cent) to produce clarification an average rise of 0.4 pH re-

TABLE III.—*pH and Suspended Solids of Sewage and Iron-Lime Sludge Mixtures*

| | Plainfield Sewage | Red Bank Sewage | Highland Park Sewage |
|---|---|---|---|
| pH Sewage | 6.5 | 7.5 | 7.2 |
| pH Increase | 0–0.5 | | |
| Suspended Solids Sewage | 596 | 340 | 387 |
| Sludge Conc. Per Cent | 1.05 | 1.65 | 1.01 |
| Sludge Returned Per Cent by Vol. | 0–10.8 | 0–10.8 | 0–10.8 |
| Susp. Sol. in Mixture | 488–2132 | 306–2784 | 352–1642 |
| Turbidity Removed by Sludge, Per Cent | 10–23 | 2–30 | 7–24 |

sulted. In no case did the rise in pH represent a very large equivalent of lime, even with excessive quantities of sludge.

The results of these experiments show that the strength of the original sewage is not a factor in determining the degree of change, but that the effect will vary from place to place. In other words, the degree of pH changes and clarification caused by returned sludge is governed by several factors which seem to depend on the character of the sewage. In some cases the return of sludge will be more effective than in others, although the total effectiveness with smaller quantities of sludge appears in any case to be small.

The sludge used in these experiments averaged about 1.2 per cent solids and the return of 5.2 per cent by volume was the lowest quantity to give maximum clarification. Only slightly poorer results were obtained using 3.6 per cent return sludge. Since the average solids content of the mixed liquor ranged between 868 and 1545 p.p.m. when these percentages were returned, it appears that the mixed liquor in the floculator should run about 1000 p.p.m. suspended solids. A return of much more than the amount necessary to give this concentration is uneconomical, both from the standpoint of pumping and flocculator speed, or air consumption when air flocculation is employed. If diffused air is used such large quantities are required to keep a high concentration of solids in suspension, that disintegration of the floc is likely to occur.

The fact that staleness of the original sewage is not important in connection with the return of a lime-iron sludge does not mean that stale return sludge is as effective as fresh sludge. As a matter of fact, either fresh sewage or stale sewage when coagulated may produce fresh sludge. This "fresh" sludge is more effective than material which has been standing, or so-called "stale" sludge. Experiments show that by the use of chlorine the sludge can be held fresh and effective.

Adding lime-iron sludge prior to $FeCl_3$ sewage coagulation showed that the resulting clarification was equivalent to the sum of the clarifying power of each. The same sewages were used for this work. The suspended solids maintained in the mixed liquor varied from 1012 to 1548 p.p.m. and varying quantities of coagulant were added. The results of three series given in Table IV show that no added clarification

TABLE IV.—*Effect of Lime-Iron Sludge on $FeCl_3$ Coagulated Sewage*

| Highland Park | | | Plainfield | | | Red Bank | | |
|---|---|---|---|---|---|---|---|---|
| Fe | Turbidity | | Fe | Turbidity | | Fe | Turbidity | |
| | No Sludge | Mixed Liquor 1548 p.p.m. | | No Sludge | Mixed Liquor 1012 p.p.m. | | No Sludge | Mixed Liquor 1132 p.p.m. |
| p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. |
| 0 | 85 | 72 | 0 | 113 | 92 | 0 | 200 | 157 |
| 2.5 | 66 | 43 | 2.5 | 50 | 43 | 5 | 108 | 83 |
| 5 | 37 | 25 | 5 | 39 | 25 | 10 | 73 | 38 |
| 10 | 20 | 10 | 10 | 25 | 10 | 15 | 57 | 20 |
| | | | | | | 20 | 37 | 10 |
| | | | | | | 25 | 10 | 5 |

was accomplished by combining the two procedures over the addition of each individually. It is also of interest that with increasing amounts of sludge the turbidity of the effluents did not vary greatly with increasing quantities of coagulant. In other words the clarification power of a given lime-iron sludge remained practically constant whether partial or nearly complete coagulation was practiced.

The return of lime-iron sludge, and its effect on lime additions, was also investigated. Sewages were treated with returned lime-ferric iron sludge and varying quantities of lime. Here again, as with the addition of $FeCl_3$, the resultant clarification was equivalent to the sum of that obtained with each procedure separately. This is shown in the examples given in Fig. 4. Increasing the quantities of return sludge raised the pH values, but no increased clarification occurred. This was probably due to the fact that with decreasing turbidities the removal of the remaining finely divided particles becomes increasingly difficult.

*Return of Acid-Ferric Iron Sludge.*—It is conceivable that acid-iron sludge would have some residual clarifying power in addition to lowering the pH value of the sewage. For that reason sewages were treated with 10 p.p.m. $FeCl_3$ and sufficient $H_2SO_4$ to produce a pH of 4.0. The resulting sludge was returned to raw sewages in quantities varying from 1.8 to 10.8 per cent of sewage volume, giving mixed liquor suspended solids concentrations varying from 336 to 2530 p.p.m. In no case was there any perceptible clarification. The maximum pH drop caused by return of sludge was 0.4 pH which took place in the case of each sewage when 10.8 per cent sludge on the basis of sewage volume was returned. This is equivalent to the pH reduction which can be obtained with about 20 p.p.m. $H_2SO_4$.

*Return of Alum-Sludge.*—When alum was used as coagulant to produce sludge, and the sludge was returned, the magnitude of its clarifying values was about the same as that obtained with ferric coagulants. Here, however, the amount returned determined the degree of clarifica-

tion (Fig. 5). This picture was changed when alum was used in conjunction with return sludge. The return of small amounts of sludge

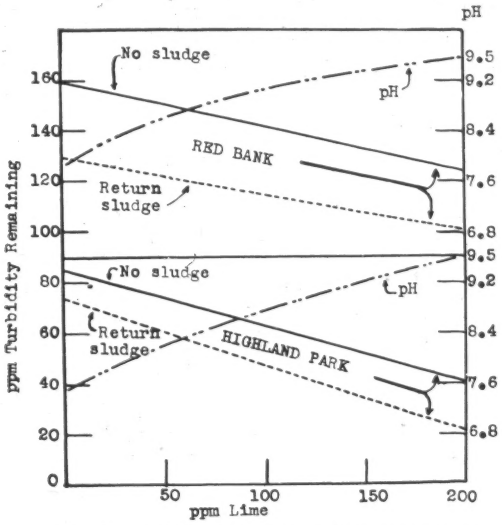


FIG. 4.—Effect of lime-iron sludge on lime requirements.

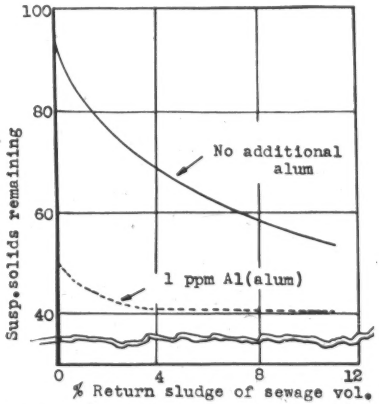


FIG. 5.—Effect of returning alum sludge (with and without additional coagulant) on clarification.

(100 p.p.m.) was beneficial, but increasing amounts did not aid clarification.

That a sludge obtained from alum coagulation is active in clarification in subsequent treatment with alum and vice versa is apparent on inspection of Fig. 6. Here again the fact is demonstrated that return

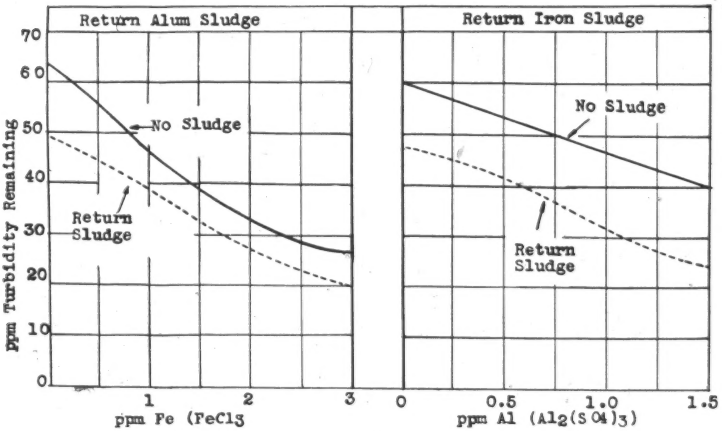


FIG. 6.—Effect of alum sludge on subsequent sewage coagulation with alum or ferric chloride.

sludge has a clarifying effect of its own. The addition of ferric coagulant tends to lessen this effect as it did with returned iron sludge, but addition of alum to iron sludge sewage mixtures did not do this.

## DISCUSSION

The preceding experimental results have shown that a definite removal of turbidity can be obtained when raw sewage is treated with coagulated return sludge. The degree of clarification is not great when compared with the amount of coagulant necessary to produce the same results. Moreover, when coagulated sludge is returned in conjunction with a coagulant the clarifying power of the sludge is obscured or may play only a minor role. However, other factors than clarification alone should be taken into consideration to arrive at an evaluation of the return of coagulated sludge in practice. The fact that either coagulated or raw untreated sewage is clarified more rapidly when coagulated sludge is returned is of importance, even if no more finely divided, non-settleable material is removed from the liquid. The rate of settling with returned sludge, together with the volumes of sludge produced by different procedures, will be discussed later. In cases where the sewage is very weak a moderate quantity of returned sludge may be beneficial. These and other advantages specific to some sewages may make the return of coagulated sludge at some plants good

practice, although no remarkable aid to clarification or considerable saving in coagulant may be found. In general it will be a question between the cost of returning the sludge and the additional benefits derived. Whenever a sufficient quantity of coagulant is added for "complete" clarification the practice of returning sludge will have comparatively little value.

The mechanism of the removal of turbidity in raw sewage by the returned sludge appears to be the coalescence of the larger non-settleable particles upon the sludge floc. The inactivity of sludge treated with excess of coagulant, over that treated with the proper amount, indicates that it is not the iron or aluminum present in the sludge that causes the clarification. If a part of the coagulant remained active it could be expected that the more coagulant added to the sludge the more effective the sludge would be, but if the coagulant is combined or fixed an excess would have no value. All results indicate that the coagulant is more or less fixed in the sludge and unless released is not capable of further coagulation. Attention has been called to this fixation in earlier work * and will be discussed in detail in a later paper.

The lower clarifying power of partially treated sludge, as compared with completely or excessively treated sludge, indicates the formation of a less tenacious floc which is held together with difficulty and is either unable to adsorb more particles or loses some of the flocculated solids. This partially treated sludge breaks up more easily when disturbed or handled.

The fact that large amounts of sludge are not more effective in clarification than smaller quantities is explained when we consider that only a definite amount of finely divided suspended solids can be removed from the liquor by the sludge. Additional sludge will remove this quantity in a shorter time, so that better results may be obtained with larger quantities of sludge (when the flocculation time is less than the customary 20 or 30 minutes) than with small quantities. Excessive quantities of sludge are actually detrimental to good clarification. This may be due to a rubbing or abrasive effect caused by contact of the individual floc particles in the liquor during flocculation. With the formation of a strong, newly coagulated floc the breaking up does not occur, even with sustained rapid mixing, but sludge coagulated at or below the optimum is more fragile, more threadlike and more readily disintegrated. With increase in density of the mixed liquor of 2000 or more p.p.m. suspended solids the flocs are in relatively close proximity, resulting in a greater chance of breaking apart.

The necessity of returning a greater weight of solids when lime-ferric chloride sludge is employed appears to be due to (1) the presence of calcium carbonate in the sludge, the absorptive power of which is small, although it adds considerable to the solids weight; (2) the lesser bulk of this type of sludge; and (3) a possible lower absorptive ability of the finely divided suspended material which was flocked out by the lime. The more compact nature of this type of floc would allow the

* Rudolfs and Setter, *This Journal*, 3, 352 (1931).

return of comparatively excessive quantities without resulting in poorer clarification.

The inactivity of the acid-iron sludge may be ascribed to the lowering of the pH value of the sewage to the point of poorest coagulation. Addition of excessive quantities of acid-iron sludge (pH 4.0) reduced the pH values of the raw sewages to only about 6.5. The decreased clarification offset the clarifying effect of the sludge, thereby yielding an effluent no better or worse than when no sludge was returned. Other factors, such as the formation of a different iron-organic matter complex, on the acid side, may determine to some extent the results obtained.

The value of acid-iron and lime-iron return sludge for adjusting pH values could be expected to be low. On addition of acid or lime to the sludge certain compounds are formed which exhibit a high buffer action. Fatty acids liberated by addition of acid may act in this way. Because of these buffering substances in the sludge the returned material is unable to exert any marked neutralizing power.

## Summary

Sewage was treated with varying quantities of sludges produced by coagulation with ferric chloride, lime and ferric chloride, and alum. Turbidity removals of from 10 to 50 p.p.m. were observed, when no additional coagulant was used, the exact removal depending upon the character of the sewage, the amount of sludge returned and the treatment used in obtaining the sludge. The average removal effected by returned sludge was from 10 to 20 p.p.m. turbidity. In the case of sludges formed by $FeCl_3$ or alum the return of sludge, sufficient to give a suspended solids concentration of about 500 p.p.m. with sewage of average strength, produced maximum clarifying action. When lime was used in addition to a coagulant, best results were obtained with about 1000 p.p.m. suspended solids in the mixed liquor. When $FeCl_3$ alone was used, with or without lime (in addition to return sludge), the clarifying effect decreased as the iron dosage increased. Additional clarification by the sludge was noted when the alum or lime dosages increased and a constant quantity of either iron or alum sludge was returned. Coagulation dosage before or after sludge was returned did not affect clarification. Excessive coagulant dosage in obtaining sludge did not render the sludge more effective, but incomplete treatment produced a less active returned sludge. Acid-ferric iron sludges were not active in clarifying sewage. Sludge of high and low pH, due to lime or acid treatment, were of comparatively little consequence in adjusting raw sewage to pH values where coagulation occurred with small coagulant dosage. This held true even when excessive quantities of sludge were used.

## Conclusions

1. Returned alum, $FeCl_3$, and $FeCl_3$-lime sludges have a definite clarifying value, although the same effect can usually be obtained with from one to five p.p.m. of the coagulant.

2. The amount of returned sludge necessary with $FeCl_3$ or alum sludge to obtain maximum clarification is lower than when lime coagulated sludge is used.

3. The order of addition of returned sludge and coagulant does not seem to be important.

4. Partially treated sludges are less effective than fully treated, and over-treated sludges are no more effective than fully treated ones.

5. Acid sludges have no clarifying values, but lower slightly the pH values of raw sewage.

6. Increasing the ferric coagulant dosage decreases the effectiveness of returned sludge in clarification.

7. The return of ferric iron or alum sludges afforded additional clarification, regardless of coagulant dosage.

# INFLUENCE OF PHOSPHORUS AND NITROGEN ON BIOCHEMICAL OXYGEN DEMAND *

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One year ago we presented data to show that the biochemical oxygen demand value of a 0.1 per cent sugar solution is greatly influenced by the mineral content of the diluting water. The data given showed that this glucose solution when diluted with plain sodium bicarbonate dilution water (300 parts per million) and inoculated with sewage organisms gave on the average only about one-eighth as great a B.O.D. as when the same diluting water was supplemented with minute amounts of mineral salts. It was also shown that little biological activity was present in the plain dilution water mixtures, as evidenced by the bacterial counts in comparison with the great activity in the supplemented dilution water mixtures, even though the number of sewage organisms used as inoculum were the same. Proof was furnished by analysis of duplicates that the mineral salts of the B.O.D. mixtures did not, in themselves, use oxygen, as no nitrates were formed during the five-day period. These analyses also demonstrated that the free ammonia nitrogen which disappeared could be found as total organic nitrogen.

This work has been continued and duplicate B.O.D. determinations made on a number of various kinds of wastes using both the plain bicarbonate dilution water and the supplemented dilution water as used in our previous work. This supplemented dilution water contains the following mineral salts:

| | | |
|---|---|---|
| Ammonium Sulphate | 2.5 | p.p.m. |
| $Ca_3(PO_4)_2$ | 0.01 | p.p.m. |
| $MgSO_4 \cdot 7H_2O$ | 0.01 | p.p.m. |
| $KH_2PO_4$ | 0.10 | p.p.m. |
| $NaHCO_3$ | 300. | p.p.m. |

and was readily prepared from a dry salt mixture as described (1). The plain bicarbonate dilution water was made by adding a concentrated solution of sodium bicarbonate to distilled water in sufficient quantity to make a concentration of 300 parts per million. Free ammonia and organic nitrogen, and soluble and total phosphorus were run on many of the samples of wastes and calculation of the concentration in the B.O.D. mixture was made. Nitrogens were titrated after distillation, where concentrations would permit; otherwise Nesslerization was used. Soluble phosphorus was measured directly after clarification, by the colorimetric method of Atkins (2). The total phosphorus was obtained by evaporation of a portion of the sample to which 1 ml. of a 10 per cent magnesium nitrate solution had been added. The dry residue was then ignited, the white ash dissolved in dilute sulphuric

* Presented before the Ninth Annual Meeting of the Central States Sewage Works Association, Indianapolis, Ind., Oct. 30, 1936.

acid and the phosphorus measured colorimetrically in a manner similar to the soluble phosphorus.

In Table I are shown results obtained on four samples of paper mill wastes and one sample of untreated domestic sewage.

TABLE I.—*B.O.D. Results of Wastes Low in Nitrogen and Phosphorus Compared to B.O.D. Results of Untreated Sewage Using Plain and Supplemented Bicarbonate Dilution Water.*

| Determinations Made | | | Results in Parts per Million | | | | |
|---|---|---|---|---|---|---|---|
| | | | Paper Mill Wastes | | | | Plain Untreated Domestic Sewage |
| | | | Sulfite Sewer No. 45310 | Ground Wood White-water No. 45311 | Ground Wood Feltwater No. 45312 | Combined Mill Effluent No. 45313 | |
| B.O.D. Plain Bicarbonate Dilution Water | | | 24 | 37 | 29 | 22 | 217 |
| B.O.D. Supplemented Bicarbonate Dilution Water | | | 50 | 156 | 82 | 102 | 221 |
| Ratio: Supplemented B.O.D. / Plain B.O.D. | | | 2.1 | 4.1 | 2.8 | 4.6 | 1.03 |
| Dilution Factors Used | A | | 12.8 | 12.8 | 12.8 | 12.8 | 77 |
| | B | | 25.6 | 25.6 | 25.6 | 25.6 | 128 |
| Concentration of Phosphorus and Nitrogen in wastes as found. | Soluble Phosphate Phosphorus | | .02 | .02 | .002 | 0 | 3.0 |
| | Total Phosphorus | | 0.39 | .06 | 0.12 | 0.16 | 4.0 |
| | Free Ammonia Nitrogen | | 2.2 | 0.18 | 0.12 | 2.0 | 13.7 |
| | Total Organic Nitrogen | | 3.0 | 3.0 | 0.5 | 1.0 | 16.5 |
| Conc. of P and N in B.O.D. mixtures due to diluted wastes (calculated) | Soluble Phosphate Phosphorus | Dil. A | .0016 | .0016 | .00016 | 0 | 0.039 |
| | | Dil. B | .0008 | .0008 | .00008 | 0 | 0.023 |
| | Total Phosphorus | Dil. A | .0304 | .0048 | .0096 | .0125 | 0.052 |
| | | Dil. B | .0152 | .0024 | .0048 | .0063 | 0.031 |
| | Free Ammonia Nitrogen | Dil. A | 0.172 | .014 | .0094 | 0.156 | 0.178 |
| | | Dil. B | 0.086 | .007 | .0047 | 0.078 | 0.114 |
| | Total Organic Nitrogen | Dil. A | 0.234 | 0.234 | .04 | .08 | 0.214 |
| | | Dil. B | 0.167 | 0.167 | .02 | .04 | 0.129 |

It will be noted that the paper mill wastes are decidedly deficient in soluble phosphorus and low in total phosphorus, while in the domestic sewage there is an abundance of phosphorus and most of it is in the soluble phosphate form. Comparing the two B.O.D. results we see that the results on the untreated domestic sewage using the two dilution

waters are well within the limits of experimental error, while in each of the wastes deficient in phosphorus, the difference between the results using a supplemented water and a plain dilution water are very great. The supplemented water containing the added phosphorus and nitrogen gives results 2.1 and 4.6 times as great as those produced using plain dilution water. It is also to be noted that the calculated concentration of soluble phosphorus furnished by the paper mill wastes to the B.O.D. mixture is decidedly below 0.02 part per million, the concentration which we previously found necessary for active bacterial growth in using the available oxygen of about 6 parts per million. The nitrogen content of two of these wastes, nos. 45310 and 45313, when diluted in the B.O.D. mixtures, is not essentially different from that found in the B.O.D. mixtures of the sewage, but in the other two, nos. 45311 and 45312, it will be seen that both are deficient in nitrogen, especially free ammonia. The deficiency of soluble phosphorus in all four of these wastes seems to be the restricting factor in the use of oxygen.

In Table II the ratio between the B.O.D. on pea canning wastes and mixtures of this waste with sewage, using plain and supplemented bicarbonate dilution water, approach unity very closely.

The concentration of phosphorus in these wastes is also seen to approach the minimal quantity of .02 part per million. Nitrogen appears to be slightly deficient in some of the higher dilutions, but in no case is this reflected in the B.O.D. result when using plain dilution water. Our work has not shown the absolute minimal quantities of these two elements that will suffice for a normal B.O.D. result, but we do feel that an adequate supply is furnished when there is .02 part per million of phosphorus and 0.2 to 0.5 part per million of nitrogen available in the diluted B.O.D. mixture. The results in Table II seem to indicate that slightly less than these amounts will suffice in some cases, depending upon the availability of these elements from their organic compounds.

In Table III are shown some apparently inconsistent results obtained at our laboratory by Mr. J. M. Holderby of the Wisconsin State Board of Health. These results were a part of a study to determine the feasiblity of treating paper mill wastes mixed with domestic sewage. All the results in this table were obtained using plain sodium bicarbonate dilution water.

In item 3 of this table will be found the actual experimental results obtained when one of these paper mill wastes (black liquor) was mixed with domestic sewage. For the unsettled wastes the B.O.D. of the mixture was found to be 820. Now from item 1 and item 2 we should have $481/2 + 280/2 = 380$ as the B.O.D. of a mixture of equal parts of these two wastes. We now know that the black liquor was deficient in nitrogen and phosphorus and the sewage carried a sufficient quota of these minerals. For this reason we believe the sewage result of 280 ppm. to be correct. On this basis if we subtract from the experimental result of 820, item 3, the B.O.D. due to sewage, and multiply the re-

TABLE II.—*B.O.D. Results on Pea Canning Waste Alone and Mixed with Settled Domestic Sewage when Plain and Supplemented Dilution Waters Were Used*

| | | | Untreated Pea Canning Waste No. 46871 | Aerated Pea Canning Waste No. 46872 | Settled Domestic Sewage No. 46873 | Mixed Filter Eff. Pea Waste and Sewage No. 46874 | Mixed Sec. Eff. Pea Waste and Sewage No. 46875 |
|---|---|---|---|---|---|---|---|
| B.O.D. Plain Bicarbonate Dilution Water | | | 940 | 850 | 121 | 271 | 267 |
| B.O.D. Supplemented Bicarbonate Dilution Water | | | 893 | 925 | 129 | 297 | 265 |
| Ratio: Supplemented B.O.D. / Plain B.O.D. | | | 0.95 | 1.08 | 1.06 | 1.09 | 0.99 |
| Dilution Factor Used | A | | 770 | 770 | 96 | 192 | 192 |
| | B | | 257 | 192 | 64 | 77 | 77 |
| Concentration of Phosphorus and Nitrogen in wastes as found. | Soluble Phosphate Phosphorus | | 2.5 | 2.0 | 2.0 | 3.5 | 4.5 |
| | Total Phosphorus | | 8.0 | 8.0 | 5.0 | 5.0 | 5.0 |
| | Free Ammonia Nitrogen | | 10.2 | 4.8 | 12.7 | 12.2 | 12.7 |
| | Total Organic Nitrogen | | 52.0 | 60.5 | 13.0 | 17.5 | 12.5 |
| Concentration of Phosphorus and Nitrogen in B.O.D. mixtures due to diluted wastes (calculated) | Soluble Phosphate Phosphorus | Dil. A | 0.0032 | 0.0026 | 0.0208 | 0.0182 | 0.0234 |
| | | Dil. B | 0.0096 | 0.0104 | 0.0313 | 0.0455 | 0.0585 |
| | Total Phosphorus | Dil. A | 0.0104 | 0.0104 | 0.0522 | 0.026 | 0.026 |
| | | Dil. B | 0.0312 | 0.0416 | 0.0782 | 0.065 | 0.065 |
| | Free Ammonia Nitrogen | Dil. A | 0.0132 | 0.00623 | 0.1324 | 0.0635 | 0.0662 |
| | | Dil. B | 0.0396 | 0.02492 | 0.1984 | 0.158 | 0.165 |
| | Total Organic Nitrogen | Dil. A | 0.0675 | 0.0785 | 0.1355 | 0.0913 | 0.065 |
| | | Dil. B | 0.2025 | 0.3140 | 0.2035 | 0.227 | 0.1625 |

TABLE III.—*5-day B.O.D. Results on Separate and Mixed Wastes using Plain Bicarbonate Dilution Water*

| Kind of Waste or Mixture | Five-Day B.O.D. as found Results in parts per million Unsettled | Settled |
|---|---|---|
| 1. Black Liquor Waste (Pulp Mill) | 481 | 433 |
| 2. Domestic Sewage | 280 | 117 |
| 3. Mixture of equal parts of Black Liquor and Domestic Sewage | 820 | 646 |

mainder by 2 we get 1360 as the B.O.D. of the black liquor rather than the 481 with plain bicarbonate dilution water. The B.O.D. of this sample of black liquor, using supplemented dilution water, was found to be 1450 p.p.m. In a similar manner the 5-day B.O.D. of the settled black liquor was found to be 1175 instead of 433, the result obtained using plain bicarbonate dilution water.

Our tables I and II show that the supplemented dilution water does not increase the B.O.D. of wastes if they contain requisite quantities of phosphorus and nitrogen. We are glad to have confirmation of this finding in results kindly furnished by Dr. W. D. Hatfield, Superintendent of Sanitary District of Decatur, Illinois. In Table IV are shown his values for biochemical oxygen demand on settled sewage and final oxidized effluent using both the plain and supplemented bicarbonate dilution waters.

It will be noted from his results that while there is a slightly greater B.O.D. using the supplemented water that the difference is negligible because, as Dr. Hatfield expressed it, "at least with our sewage the necessary elements are added to the standard bicarbonate dilution water by the sewage itself." *We wish in this connection to make it distinctly clear that we are not advocating the addition of supplementary mineral salts to the bicarbonate dilution water because we expect to get a higher or different result with domestic sewage and its effluents, but because we want to have used generally a dilution water which will measure the biochemical oxygen demand of all wastes by the same yardstick under identical growth conditions regardless of the kind of waste tested.* Stream waters reported in the literature contain sufficient phosphorus and nitrogen for optimal oxidation of these wastes deficient in nitrogen and phosphorus. Our analysis of samples collected by Sanitary Engineering Department of Wisconsin State Board of Health, under direction of Mr. Warrick, taken at twelve stations on the Baraboo River, during the past summer (1936) have shown from .02 to 0.32 parts per million of soluble phosphate phosphorus.

In Table V are shown the phosphorus and nitrogen content of various stream waters in Wisconsin which receive pulp and paper mill waste. These waters are rather representative of the natural waters in the state. It will be noted that these receiving waters carry an adequate supplement of both phosphorus and nitrogen.

It is only logical that these wastes deficient in the mineral constituents of phosphorus and nitrogen be subjected to the same growth and mineral conditions in the testing procedure as they will meet in the stream which receives them if we are to know their oxygen demand on that stream. *It is only under such testing conditions that one waste can be compared with another and that sewer rental laws can be applied with justice.*

TABLE IV.—*Dr. Hatfield's Results on Settled Sewage and Final Secondary Settled Effluent*

| Date 1936 | Results in parts per million | | | | | |
|---|---|---|---|---|---|---|
| | Settled Sewage 3 and 4 per cent dilution used | | | Final Effluent 10 per cent dilution used | | |
| | 5-day B.O.D. Using Plain Bicarbonate Dilution Water | 5-day B.O.D. Using Supplemented Dilution Water | Difference in P.P.M. B.O.D. | 5-day B.O.D. Using Plain Bicarbonate Dilution Water | 5-day B.O.D. Using Supplemented Dilution Water | Difference in P.P.M. B.O.D. |
| July 3 | | | | 21 | 19 | −2 |
| 4 | | | | 7 | 12 | 5 |
| 5 | | | | 14 | 15 | 1 |
| 6 | 191 | 197 | 6 | 24 | 33 | 9 |
| 7 | 153 | 189 | 36 | 16 | 19 | 3 |
| 8 | 119 | 123 | 4 | 12 | 10 | −2 |
| 9 | 127 | 142 | 15 | 7 | 10 | 3 |
| 10 | 96 | 93 | −3 | 12 | 19 | 7 |
| 11 | 62 | 73 | 11 | 9 | 7 | −2 |
| 12 | 142 | 160 | 18 | 17 | 24 | 7 |
| 13 | 114 | 127 | 13 | 40 | 38 | −2 |
| 14 | ..... | OMIT ..... | | 20 | 32 | 12 |
| 15 | 152 | 156 | 2 | 16 | 18 | 2 |
| 16 | 154 | 156 | 2 | 28 | 29 | 1 |
| 17 | 156 | 166 | 10 | 30 | 29 | −1 |
| 18 | 141 | 148 | 7 | 30 | 32 | 2 |
| 19 | 86 | 90 | 4 | 18 | 18 | 0 |
| 20 | 85 | 90 | 5 | 18 | 22 | 4 |
| 21 | ..... | OMIT ..... | | 41 | 43 | 2 |
| 22 | 110 | 120 | 10 | 16 | 16 | 0 |
| 23 | 127 | 150 | 23 | 31 | 30 | −1 |
| 24 | 152 | 166 | 14 | 24 | 28 | 4 |
| 25 | 94 | 100 | 6 | 12 | 15 | 3 |
| 26 | 92 | 103 | 11 | 16 | 19 | 3 |
| 27 | 104 | 112 | 8 | 13 | 14 | 1 |
| 28 | 126 | 128 | 2 | 21 | 21 | 0 |
| 29 | 116 | 123 | 7 | 12 | 16 | 4 |
| 30 | 141 | 152 | 11 | 20 | 20 | 0 |
| 31 | 146 | 162 | 16 | 17 | 19 | 2 |
| Aug. 1 | 152 | 156 | 4 | 20 | 22 | 2 |
| 2 | 92 | 97 | 5 | 9 | 13 | 4 |
| 3 | 192 | 193 | 1 | 22 | 21 | − 1 |
| 4 | 144 | 148 | 4 | 15 | 17 | 2 |
| 5 | 128 | 136 | 8 | 23 | 25 | 2 |
| 6 | 166 | 160 | −6 | 19 | 19 | 0 |
| 7 | 186 | 189 | 3 | 16 | 20 | 4 |
| 8 | 142 | 153 | 11 | 13 | 14 | 1 |
| 9 | 161 | 179 | 18 | 26 | 30 | 4 |
| 10 | 159 | 166 | 7 | 20 | 22 | 2 |
| 11 | 166 | 179 | 13 | 19 | 20 | 1 |
| 12 | 189 | 206 | 17 | 27 | 28 | 1 |
| 13 | 117 | 120 | 3 | 11 | 12 | 1 |
| TOTAL ..... | 4988 | 5185 | 197 | 802 | 890 | 88 |
| AVERAGE DAY ..... | 135 | 140.5 | 5.5 | 19.1 | 21.2 | 2.1 |
| PER CENT DIFFERENCE ..... | | 4% | | | | 11% |

TABLE V.—*Phosphorus and Nitrogen Content of Wisconsin Stream Waters*

| Name of River-sampling Point | Results in parts per million | | | | |
|---|---|---|---|---|---|
| | Soluble Phosphate Phosphorus | Total Phosphorus | Nitrogen as | | |
| | | | Free Ammonia | Organic | Total |
| Chippewa River (Chippewa Falls) Above Wissota Dam | 0.04 | 0.04 | 0.23 | 0.28 | 0.51 |
| Chippewa River (Eau Claire) At Shawtown Bridge | 0.06 | 0.06 | 0.36 | 0.19 | 0.55 |
| Chippewa River (Eau Claire) Above dam-above Eau Claire | 0.06 | 0.10 | 0.19 | 0.31 | 0.50 |
| Fox River (Green Bay) At G. B. and W. Bridge | 0.04 | 0.05 | 0.46 | 0.19 | 0.65 |
| Menomonee River (Marinette) At Main St. Bridge, Menomonee | 0.03 | 0.05 | 0.14 | 0.54 | 0.68 |
| Wisconsin River (Mosinee) Above Dam | 0.02 | 0.22 | 0.63 | 0.68 | 1.31 |
| Fox River (Neenah) Above Neenah | 0.15 | 0.18 | 0.90 | 0.41 | 1.31 |
| Wisconsin River (Nekoosa) Above Dam | 0.02 | 0.10 | 0.26 | 0.77 | 1.03 |
| Menomonee River (Niagara) Above Dam | 0.06 | 0.06 | 0.52 | 0.43 | 0.95 |
| Flambeau River (Park Falls) Above Dam | 0.04 | 0.04 | 0.18 | 0.52 | 0.70 |
| Flambeau River (Park Falls) At First Dam Below City | 0.02 | 0.08 | 0.27 | 0.27 | 0.54 |
| Peshtigo River (Peshtigo) Below Peshtigo | 0.02 | 0.04 | 0.22 | 0.64 | 0.86 |
| Wisconsin River (Rhinelander) Above Dam | 0.04 | 0.05 | 0.29 | 0.45 | 0.74 |
| Wisconsin River (Rhinelander) First Bridge Below City | 0.05 | 0.13 | 0.19 | 0.55 | 0.74 |
| Wisconsin River (Stevens Point) Below City | 0.02 | 0.15 | 0.26 | 0.64 | 0.90 |

REFERENCES

1. Wm. L. Lea and M. Starr Nichols, "Influence of Substrate on Biochemical Oxygen Demand," *This Journal*, 8, 435–447 (May 1936).
2. W. R. G. Atkins, "The Phosphate Content of Fresh and Salt Waters in Its Relationship to the Growth of Algal Plankton," *Journal Marine Biolog. Assoc., England*, 13, 119 (1923). (Method on p. 144.)

# Plant Operation

## COMPARISON OF SEWAGE PURIFICATION BY COMPRESSED AIR AND MECHANICALLY AERATED ACTIVATED SLUDGE *

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### III. Discussion of Results and Opinions

In the first sections [21, 22] of this paper, results were given to show comparative purification efficiencies and operating costs of mechanical aeration by brushes compared with spiral circulation by compressed air. In view of the many divergent opinions cited in the literature on the subject, it is thought to be of interest to discuss these results in the light of previous findings, and also in relation to some of the more specific factors, such as the major source of oxygen absorption and core formation. For this purpose the results have been divided into the following topics: (*a*) oxygen absorption from bubbles versus surface absorption, (*b*) power consumption, (*c*) capital cost, (*d*) purification, (*e*) core formation, and (*f*) settling characteristics of activated sludge floc.

#### Oxygen Absorption from Bubbles Versus Surface

The question which probably has aroused the greatest interest, and which is of fundamental importance in determining which type of aeration is the most economical and efficient, is whether more oxygen is absorbed from air bubbles rising through the liquid than is absorbed from the atmosphere at the liquid surface of the aerator.

Investigators have expressed different opinions on this question. Fowler and Chaterjee [9] concede that aeration occurs at the upper liquid surface when the bubble breaks, but their laboratory results indicated that most oxygen was absorbed from ascending air bubbles. Scouller and Watson [18] go further and say that "oxygen requirements of activated sludge plants are so large they cannot be satisfied by surface aeration. Oxygen absorbed per square meter of bubble surface per 24 hours is three times the amount absorbed through an exposed surface." On the other hand several investigators believe the contrary to be true. Hayworth [10] states "experiments indicate the bulk of oxygen solution occurs at disturbed and changing surfaces and not directly from bubbles." Buswell [3] states that the oxygen film at the water surface is very important and [4] he has reported that sewage sludge can be activated without compressed air agitation. Buswell, Shive, and

* Journal Series Paper N. J. Agricultural Experiment Station, New Brunswick, N. J., Division Water and Sewage Research. (For first two papers of this series, see *This Journal*, Vol. VIII, pp. 766 (September) and 924 (November), 1936.

Neave [5] state "in compressed air the rising air bubbles are effective only on the thin film around them. Mechanical agitation breaks up the air-saturated films and replaces them by new surfaces."

Kessener and Ribbius [13] indicate from their experiments that in clean water a compressed air installation gives a rate of oxygen supply about four times greater than surface aeration. But with sewage this rate drops to an amount hardly any higher than surface aeration. A possible explanation is that sewage colloids cover the air bubbles in a diffused air plant. Dallyn and DelaPorte [7] conclude that "agitation in absorbing oxygen from air accounts for only a fraction of the oxygen supply, about 25 per cent coming from air used for agitation and 45.6 per cent from surface absorption."

The results presented in previous sections of this paper show quite conclusively that the contentions of some of the authors cited are entirely out of line with the facts found in this investigation. The statement of Scouller and Watson that surface aeration cannot support the oxygen requirements by one-third of the amount required is definitely not substantiated. The results of this study show that surface aeration will not only provide adequate oxygenation for good purification but will supply more oxygen to the aerators at a lower cost than with a diffused air installation. Our results also fail to support the views of Fowler and Chatterjee that "most aeration takes place from ascending air bubbles." If this were the case compressed air would be superior to mechanical circulation in a spiral circulation plant by absorption of oxygen not only from ascending air bubbles but also from the surface. This is not supported by the results of this investigation. On the contrary, the data show that more oxygen was absorbed from the atmosphere than from the rising bubbles. This is confirmed by the fact that the brush aerators provided a greater supply of dissolved oxygen to the tank under all conditions of operation with less power consumption than the compressed air.

## Power Consumption

Power consumption by the aerating devices is of predominant importance in comparison of aeration systems. Cost of power constitutes a major part of the total cost of operation of an activated sludge plant. The majority of reports to date indicate that aeration by mechanical devices is a cheaper method of aeration than compressed air. Bolton [2] reported a consumption of 15 H. P. per million gallons of sewage "which was considerably less than the power consumption for compressed air at that time." Peck [16] claimed that "mechanical devices for aeration were low in power consumption." Butler and Coste [6] concluded that the most efficient form of aeration was mechanical apparatus with separate reaeration of diffused air tanks. Heyworth [10] found that "it is more economical to produce surface agitation with paddles or screws than with diffused air." Stanley [20] concluded that power costs are about the same for each type. Sanford,[17] however,

claimed that air blowing is more economical in every way. Most of these opinions, however, were based upon comparisons of costs between plants in different locations which were not operating under identical conditions with respect to sewage flow rates, character of sewage, detention periods, method of operation, and equal purification results. Consequently the results would not be directly comparable, and definite conclusions as to relative power savings could not be given because of the effect of these variable factors.

The results of our investigation, which was conducted under practically identical conditions of design and operation, showed quite definitely that mechanical aeration by means of brushes was cheaper in power cost than diffused air for equal purification results. The average results over a six-month period, with equal purification of sewage, showed power consumption by the brushes to be at least 18 per cent less than for the air-diffusion unit for the minimum degree of purification and 22 per cent less for the maximum degree of purification. Moreover, greater residual dissolved oxygen was maintained in the brush aerators in both instances, showing that with equal residual dissolved oxygen in the tanks the power consumption for the brushes related to compressed air would be even less than the figures shown.

It is also difficult to correlate these results with the conclusions of Besselievre and Sierp. Sierp[19] concludes that "air is utilized most efficiently by using paddles in combination with compressed air." Besselievre[1] states that "the cost of compressing air is 35 to 50 per cent of the total operation cost, of which only 5 to 10 per cent is used for oxidation." On this basis he concluded that a combination of air and stirring reduces the cost.

If 90 to 95 per cent of the power consumed is used for agitation and circulation and only 5 to 10 per cent for oxidation of sewage and support of biological life in the sludge floc, the major work of the aerating device is spent for the mechanical purpose of circulating and mixing. If the mechanical type of aeration is the most efficient for 90 to 95 per cent of the work and at the same time will provide sufficient oxygen, as shown by these and other investigations, to support the biological activities, it is difficult to see why greater efficiency can be gained by combining mechanical devices with a greater efficiency and compressed air diffusion of lesser efficiency.

## Capital Cost

Reports on cost of construction of mechanical versus diffused air activated sludge plants have varied. An editorial in 1922 in the *Municipal Engineer and Sanitary Record*[8] states that "the capital cost of installation favors mechanical agitation rather than diffused air." Sanford[17] in the same year took exception to this statement, saying that air blowing is more economical in every respect. As late as 1929, the New York Board of Estimate Committee[15] reported that "surface

agitation requires shallow tanks and large area, hence construction costs would be higher."

The data in our investigation show that (*a*) the difference in cost of actual aerator construction including aerating devices is negligible, amounting to only a fraction of a per cent of the total plant cost; (*b*) the statement "surface aeration requires shallow tanks and large area" is not substantiated. The studies have shown that more dissolved oxygen can be maintained in the aerators with brushes than with air, in exactly the same size tanks, with lower power consumption. This is further confirmed by Kessener and Ribbius,[12] who show that for equal conditions of temperature and oxygen deficiency the oxygenation capacity of an aerator is directly proportional to the equivalent aeration area (area/volume) for either type of aeration. This means that if the exposed surface aera can be changed with mechanical devices a sufficient number of times to be equal to the equivalent surface area of a diffused air plant at the same power cost, then the size of the tank is not a factor. These investigations confirm this, in that the brushes produced a larger relative surface area at lower power costs in the same size tank.

From the standpoint of total plant construction cost, however, where sludge digestion and sand bed drying are to be included, it is apparent that the cost of plant construction would be larger for the brush type of aeration. This increased capital cost for the brushes would be due to the higher moisture content of the activated sludge, requiring greater capacities principally in settling tanks and digestion tanks.

## Purification

The only reference found by the authors in the literature dealing in a specific manner with comparative purification of mechanical and compressed air aeration was that of Peck,[16] who claimed that the "violent agitation produced by means of mechanical devices is destructive to some organisms and tends to produce increased turbidity." Makepeace [14] "confirmed the belief that eighty per cent of the purification is effected in two hours by diffused air, mechanical devices being more efficient for complete treatment."

The studies in this investigation confirm the findings of Peck, within certain limits, with respect to increased turbidity by mechanical aeration devices. With higher concentrations of activated sludge solids (above 3,000 p.p.m.) this does not hold. But below 3,000 p.p.m., increased turbidity of the effluent was found to occur in more or less a straight line ratio with decreasing amounts of activated sludge. Except for the difference in suspended solids removal, the purification was practically identical with each aerator. The claim of Makepeace that "eighty per cent of the purification is effected in two hours by diffused air" implies that a similar reduction could not occur with mechanical devices. The results of this investigation show that the rate of purification by brushes and compressed air was equal in all respects, with the exception of suspended solids removal.

## Core Formation

Core formation, if existing in an aeration tank, influences either the quality of the plant effluent or the power consumption or both. The effect of a center "core" of liquid moving forward longitudinally in the aerator is to produce improper mixing of activated solids and sewage and improper mixing of air with the solids and sewage. The net result of this action, if present to great extent, is either to reduce the quality of the effluent with a given power consumption or to create the necessity for greater power consumption for equal quality of effluent. Transverse mechanical aerating devices and spiral flow compressed air installations are theoretically particularly suited to this "core" action by virtue of their principle of operation. The force of action of the mechanical aerators is confined to a small layer of liquid at the surface of the tank, which creates a tendency to produce maximum velocities in the peripheral layers of the rotating liquid with diminishing velocities toward the center of the tank. Spiral circulation compressed air installations theoretically should give a similar action. The more hydraulically perfect the installation is for efficient circulation, the greater the theoretical tendency should be for short-circuiting by "core action."

Our investigations showed that the distribution of velocities of circulation with both types of aeration produced a tendency for core formation. The higher circumferential velocity is marked in both cases by a gradual decrease in velocity from the outer layers to a minimum velocity somewhere near the center of the tank. This is illustrated very clearly by a cross-sectional comparison between the average velocities in the outer third with the average velocities in the middle third. If the data are compiled in this manner the following relationship is shown:

| | H.P. | Ratio: $\frac{\text{Av. Outer velocity}}{\text{Av. Middle velocity}}$ |
|---|---|---|
| Air | 4.2 | 3.45 |
| Air | 7.8 | 3.94 |
| Air | 11.5 | 3.85 |
| Brushes | 4.0 | 7.6 |
| Brushes | 7.0 | 9.3 |
| Brushes | 10.0 | 12.2 |

These figures show that the tendency for core formation exists in both aerators. It is more pronounced with brushes than with compressed air. The tabulation also shows that the tendency for core formation with the brushes is more pronounced with increasing velocities and applied power. The ratio for the brushes increased by over 60 per cent with increase in applied power from 4.0 H.P. to 10.0 H.P.; the ratio of the velocities with compressed air increased only a little over 11 per cent for practically the same range of power increase. This latter fact would indicate more lateral diffusion of the air bubbles with increasing air and applied power which results in more uniform distribution of velocities and less tendency for core formation with the compressed air.

The previous data on circulation velocities indicate that core formation in the brush aerators was more noticeable than in compressed air tanks, and therefore distribution of dissolved oxygen with the brush aerators was less uniform than with compressed air. The data on dissolved oxygen distribution in the aerators, obtained coincidentally with the velocity measurements, show, however, a different picture. The residual dissolved oxygen content at all points in the same vertical plane is almost identical for the brush type of aeration, but for the compressed air there is a decided tendency for a "core" effect. The dissolved oxygen in the middle of the compressed air tank was consistently lower than at the circumference. This deviation amounted to a maximum of 77 per cent. These results seem paradoxical in nature in that the type of aeration with the most pronounced stratification of velocities gave greatest uniformity of dissolved oxygen distribution. The explanation for this anomaly apparently lies in the presence of eddies or turbulence of the liquid coincident with the main direction of the rotation velocities. This condition of turbulence would necessarily accompany high differentials between stratification velocities. Kessener [11] reached a similar conclusion in salt tests on short-circuiting of aeration tanks. His conclusions were that with the brush type of aeration (a) there is no danger of absolute short-circuiting and (b) mixing is very strong. His explanation was that the thorough mixing of the tank contents was due to the rapid movement of one part of the water being compensated for by the slower movement of another part, giving the effect of "relative short-circuiting" or mixing.

## Settleability of Sludge Floc

One of the most outstanding differences in results from the two types of aeration lies in the settling characteristics of the activated sludge floc. The authors have been unable to find any reference in the literature to this factor in comparison of the relative merits of different types of aeration. This lack of data has been apparently due to the difficulty of comparing data due to varying characteristics of sewage and operation at different plants.

The principal effect of this difference in settling and compacting value of the sludge floc would apply to the capacities of certain plant units.

The units which are particularly affected are the final settling tanks and the sludge digestion tanks, especially in the absence of any concentration facilities.

The differences in solids content of 300 per cent found in this instance between the brush and compressed air sludge, or 0.26 per cent and 0.77 per cent, respectively, have required from 50 to 75 per cent greater sludge digestion capacity for the less dense sludge when fed directly to the digestion tanks. When the sludge is wasted through preliminary settling tanks, or concentration tanks, the additional capacity required is somewhat less, but is still an important item.

With respect to the final settling tanks, the effect of the decreased density of the sludge floc is more or less proportional. The capacity

of the settling tanks is theoretically cut down in direct proportion to the additional volume occupied by the sludge when settled to the maximum concentrated amount in a length of time equal to the detention period. To allow equivalent settling time and flow-through area for the two activated sludge flocs the volume of the settling tank must be increased for the less dense sludge. Or, if the size of the settling tank is to be maintained the same, the rate of sludge removed must be increased to compensate for the difference in volume occupied by the sludge. By this latter operation an increase in capacity of the aerators is required to maintain an equal aeration period with the increased volume of sludge return. The latter alternative is also limited by the rate of settling of the activated sludge to the final compacted value. If the rate of settling of the floc of higher moisture content is slower, then additional settling capacity is required in addition to the higher rates of sludge removal. In the case of the plant used in these studies, it was found by experience that to compensate for the lighter quality of the floc found by the brush aerators, the final settling tank had to provide from 2 to 2½ hours detention period to prevent sludge floc from being scoured over the final settling tank weir, as against from 1 to 1½ hours for the compressed air floc. In addition, the rate of return sludge had to be increased with the use of the brush aerators by from 8 to 10 per cent over the rate used with the compressed air.

From the foregoing discussion it appears that the applicability of each type of aeration is specific, depending upon the operating conditions.

Where power operation costs are of paramount importance the brush type of aeration is the best by reason of the lower power consumption.

Where sludge digestion and sand bed drying are to be provided for the waste activated sludge, the compressed air installation will allow cheaper total capital cost of the plant by virtue of the lower capacities required in sludge digestion tanks and sand drying beds.

Where both operation costs and capital costs are of importance, the increased cost of construction of a brush aeration plant should be balanced against its lower cost of operation.

Circumstances where the brush type of aeration would be superior, by virtue of lesser power costs would be:

(*a*) In simple aeration,
(*b*) With standby or auxiliary aeration facilities,
(*c*) Where volume of sludge handled is not of importance.

## General Summary

From data and experiences obtained with mechanical aeration by brushes and compressed air aeration with porous tubes it is apparent that a single broad statement of the comparative merits of the two types cannot be made. Each type possesses certain advantages for one situation which may be offset by accompanying disadvantages for another.

From the standpoint of purification, the results were approximately equal with respect to both degree and rate of purification with the use of high concentrations of activated sludge solids. With lower amounts of solids the purification results were likewise equal, with the exception of suspended solids removal. The suspended solids content of the effluent from the brush aerator was greater than that of the effluent from the compressed air tank, with the use of lower amounts of activated sludge solids. With activated solids at approximately 3,000 p.p.m., the percentage suspended solids removal from the settled sewage was the same for the compressed air and the brushes. However, with activated solids below 3,000 p.p.m. the difference in suspended solids removal between the two aerators increased as nearly a straight line function to the decrease in amount of activated solids, until at 1,200 p.p.m. the suspended solids removal on the basis of the settled sewage was 73 per cent for the air and only 56 per cent for the brushes, or a difference of 17 per cent removal efficiency. All other indicies of purification such as B.O.D. and $NH_3$-reduction and nitrate formation were the same for each type of aeration under all equivalent conditions of operation.

The most striking difference in operating characteristics of the two types of aeration was found to be in the settleability of the activated sludge floc. With the use of compressed air, the settleability of the activated floc was three times as great as the settleability of sludge formed with the brushes. This is of particular importance since the activated sludge must be treated in auxiliary units and the capacities of the units are thereby affected by the volume occupied by the sludge.

Average circulation velocities were approximately the same for each type of aeration with equal power consumption, but surface and bottom velocities were higher for the brush type of aeration. The difference in velocity of circulation at the surface was reflected in more economical oxygen supply to the aerator. Under equal conditions of operation the brushes supplied nearly 100 per cent more residual dissolved oxygen to the tanks than did the air, with the same power consumption. In addition, the distribution of dissolved oxygen was very uniform with the brushes as compared with a tendency for core formation with the porous tubes.

From the standpoint of operating cost of purification the data showed mechanical aeration by brushes to be the more economical. On the basis of average conditions of operation and equal purification of sewage throughout the year, it was found that power consumption was from 18 to 22 per cent less with brushes than with compressed air.

Operating superintendance was the same for each type of aeration. Labor cost of aerator attendance was also approximately the same. Because of the lighter sludge floc formed by the brush aerator a slightly increased cost of waste sludge disposal can be expected for equal results, due to the increased volume of sludge.

The capital cost of aerator construction was approximately the same for either type of aeration. The difference in cost of apparatus

for application of the air to the sewage was only a fraction of a per cent of the total plant cost. This difference in capital cost might be extended, however, to a major amount by necessity for increased capacity in other plant units due to the lighter sludge formed with the brush aeration. The more voluminous sludge requires greater final settling tank capacity, greater capacity of sludge return equipment, larger sludge digestion tanks, and more sludge drying bed area. The extent of this additional cost would be difficult to estimate for general application because of difference in character of sewage, method of operation, facilities for concentration of the sludge, etc., but experiences at this plant would dictate that at least 50 per cent greater sludge digestion, sludge return, and sludge drying bed capacity would be required for the lighter sludge of the mechanical brush aerators. Also for the final settling tank a detention period of at least 2½ hours is required.

The applicability of the two types of aeration depends upon the nature of operating conditions.

Where power costs are of importance the mechanical aeration by brushes is the best by reason of lesser power consumption.

Where both operation costs and capital costs are of importance, the increased cost of plant construction due to larger capacities required for digestion tanks, sand drying beds and final settling tanks for the brush type of aeration should be balanced against the decreased cost of plant operation.

Circumstances where the brush type of aeration would be superior, by virtue of lesser power costs would be:

(*a*) In simple aeration,
(*b*) With standby or auxiliary aeration facilities,
(*c*) Where volume of sludge handled is not of usual importance.

REFERENCES

1. Besselievre, *Water Wks. and Sew.*, **80**, 364–366 (1933).
2. Bolton, *Proc. Assoc. Mgrs. Sewage Dis. Wks.*, 61 (1922).
3. Buswell, *Eng. News Rec.*, **90**, 835–837 ((1923).
4. Buswell, *Eng. News Rec.*, **90**, 817 (1923).
5. Buswell, Shive, and Neave, *Univ. Illinois Bull.* **25**, 22 (1928).
6. Butler, and Coste, *Jour. Soc. Chem. Indust.*, **46**, 49T–59T (1927).
7. Dallyn, *Int. Conf. Sanit. Engin.*, 279–288 (1924).
8. Editorial, *Munic. Engin. and Sanit. Rec.*, **70**, 153–154 (1922).
9. Fowler, *Eng. News Rec.*, **99**, 922 (1927).
10. Heyworth, *Eng. and Contract.*, **56** (1931).
11. Kessener, *Ann. Rept. Dutch Govt. Inst. for Purification of Waste Waters*, 1933.
12. Kessener, and Ribbius, *Tech. Gemeindeblatt*, **37**, 205 (1934).
13. Kessener, and Ribbius, *This Journal*, **6**, 423 (1934).
14. Makepeace, *Proc. Assoc. Mgrs. Sewage Disp. Wks.*, 96 (1928).
15. New York Board of Estimate, *Comm. Rept. on Activated Sludge Plants*, 1929.
16. Peck, *Eng. News Rec.*, **90**, 522–526 (1923).
17. Sanford, *Canad. Engin.*, **43**, 608–610 (1922).
18. Scouller, and Watson, *Surveyor*, **86**, 15–16 (1934).
19. Sierp, *Gesundh. Ingen.*, **4**, 23 (1926).
20. Stanley, *Proc. Ninth Tex. Water Wks. Short School*, 288–292 (1927).
21. Ridenour and Henderson, *This Journal*, **8**, 766 (Sept., 1936).
22. Ridenour and Henderson, *This Journal*, **8**, 924 (Nov., 1936).

# TRICKLING FILTER LOADINGS *

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Trickling filters have established an enviable reputation for service in the field of sewage treatment. Regardless of the extremes of their loadings they have given commendable service.

During the years of operation the design loadings have covered a wide range and there is still a marked difference of opinion as to their limits. This study has been made to investigate operating loadings in Ohio.

## Sewage and Loading Expressions

The volume of sewage treated in relation to population served varies widely and affects the purification results. Likewise, the strength of sewage varies with the water consumption and the industrial load. It is necessary to take account of these differences and list them as loadings expressed on a basis of population, flow and strength.

The number of persons per acre foot has been a common measure of loading for trickling filters but this measure of loading does not take into consideration the strength of industrial wastes.

Gallons per acre or per acre foot has an important place in trickling filter loadings. To date the true hydraulic limits of dosing a filter have not been definitely settled.

Pounds of oxygen demand per acre foot or per 1000 cu. ft. measures the effect of industrial with sanitary wastes. This measure of oxidation required to stabilize the sewage, as determined by the 5-day B.O.D. affords an opportunity for dependable comparison of loadings.

Using these three expressions of loadings, tables are presented here for several Ohio sewage plants. Yearly average figures are used, as time limits the examination of monthly and seasonal variations.

## Factors Affecting Purification

The factors which affect the performance of trickling filters are: the size, character and depth of media; the temperature of the air and sewage; the strength and volume of the applied flow; the ventilation and cleanliness of media; the method of distribution; and seasonal variations. Although there is considerable difference of opinion as to the relative influence of these factors, it appears that distribution, volume of application and ventilation afford the greatest possibility for increased effectiveness.

## Modifications of Filtration

Modifications of the conventional process of filtration have appeared and must be considered. They are: recirculation of filter effluent; re-

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circulation of filtered solids (from the secondary tanks); addition of chemicals; and pre-aeration of the applied sewage. While the available data on these modifications are limited in Ohio, they must not go untried for they offer possibilities in the control of flies, odors and other objectionable adjuncts of the trickling filter, to say nothing of their effects upon loadings.

In Table I are given the essential design data for the trickling filters considered in this study. As has been previously noted, there is a difference of over 100 per cent between the extremes, both on gallonage and population.

TABLE I.—*Designed Loadings for Trickling Filters of Selected Ohio Sewage Treatment Works*

| City | Total Area Acres | Av. Depth | Total Acre Feet | Pop. Designed for | Pop. Per Acre | Pop./ Acre Foot | Des. Flow m.g.d. | Dos. m.g.d./ Acre | Dosage m.g.d./ Acre Ft. |
|---|---|---|---|---|---|---|---|---|---|
| Akron | 14.0 | 10′ | 140 | 260,000 | 18,600 | 1,860 | 33.0 | 2.35 | 0.235 |
| Alliance | 1.26 | 10′ | 12.6 | 36,000 | 28,600 | 2,860 | 5.4 | 4.3 | 0.43 |
| Canton | 6.75 | 7′ | 47.25 | 135,000 | 20,000 | 2,857 | 13.5 | 2.0 | 0.286 |
| Cleveland, Southerly | 6.0 | 10′ | 60 | 240,000 | 40,000 | 4,000 | 24.0 | 4.0 | 0.400 |
| Delaware | 0.55 | 8′ | 4.4 | 14,500 | 26,300 | 3,300 | 1.45 | 2.63 | 0.33 |
| Fostoria | 0.82 | 7.2′ | 5.91 | 15,000 | 18,300 | 2,540 | 2.0 | 2.44 | 0.34 |
| Marion | 1.4 | 10′ | 14.0 | 40,000 | 28,600 | 2,850 | 4.0 | 2.85 | 0.285 |
| Norwalk | 0.394 | 8′ | 3.15 | 8,000 | 20,300 | 2,540 | 1.0 | 2.54 | 0.317 |

In Table II and III are listed the operation data for the past five-year period, covering year round performance except where otherwise noted.

In Table IV plant efficiencies together with filter efficiencies are tabulated. The reduction in suspended solids, 5-day B.O.D., free ammonia and organic nitrogen are listed.

## DISCUSSION

The data obtained from these plants show that the effectiveness varies inversely to the strength and quantity of the sewage applied. An increase in filter loading in lb. B.O.D. per 1000 cu. ft., together with a conventionally high dosage as M.G.D./acre-foot, cause a decrease in efficiency. While these trickling filters were designed for flows of 2 M.G.D./acre or 0.3 to 0.4 M.G.D./acre-foot, in most cases it appears that those favored by lesser flows and also B.O.D. loads under 5 lb./1000 cu. ft. produce the best results. The filter effluents must be judged along with the filter efficiencies for there are cases where the sewage strength favors higher efficiencies but with production of an inferior effluent. Filter effluents having a 5-day B.O.D. less than 40 p.p.m., with a dissolved oxygen of 4 or more p.p.m. and with several parts of nitrites and nitrates, will prove stable under most conditions when given final sedimentation, plus chlorination, if no dilution is afforded.

TABLE II.—*Operation Data for Ohio Sewage Treatment Plants During Period 1931–1935*

| Location | Year | Weeks Filters Operated | Average Treat. Flow M.G.D. | Population Served 1000's | 5 Day B.O.D.—20 °C. in p.p.m. | | | | Nitrites and Nitrates p.p.m. N. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Raw | Settled | Filtered | Fin. Eff. | |
| Akron | 1931 | 51.6 | 28.1 | 179.4 | 150 | 109 | 20.8 | 15.8 | 3.65 |
| | 1932 | 50.3 | 31.2 | 181.6 | 137 | 121 | 25.0 | 16.8 | 4.65 |
| | 1933 | 50.0 | 31.4 | 186.8 | 155 | 105 | 24.0 | 17.2 | 5.76 |
| | 1934 | 52.0 | 27.7 | 186.8 | 188 | 127 | 26.7 | 17.7 | 7.28 |
| | 1935 | 52.0 | 29.6 | 193.6 | 171 | 120 | 26.5 | 18.4 | 8.68 |
| Alliance | 1931 | 50.3 | 2.070 | 23.60 | 197 | 132 | 25 | 17 | 11.97 |
| | 1932 | 50.2 | 1.889 | | 232 | 150 | 27 | 18 | 11.79 |
| | 1933 | 50.3 | 1.887 | | 236 | 140 | 38 | 24 | 11.82 |
| | 1934 | 51.1 | 1.821 | | 268 | 166 | 33 | 25 | 12.34 |
| | 1935 | 48.7 | 1.833 | 21.40 | 215 | 138 | 36 | 27 | 8.71 |
| Canton | 1931 | 39.0 | 9.25 | 100.0 | 208 | 127 | 27 | | 9.4 |
| | 1932 | 52.0 | 10.19 | 103.0 | 189 | 111 | 31 | | 11.5 |
| | 1933 | 43.3 | 9.27 | 104.0 | 215 | 129 | 32 | | 13.4 |
| | 1934 | 39.0 | 9.41 | 104.0 | 251 | 136 | 31 | | 11.6 |
| | 1935 | 30.3 | 10.43 | 104.0 | 201 | 111 | 30 | | 12.3 |
| Cleveland, Southerly | 1931 | 52.0 | 10.92 | 130 | 153 | 106 | 28 | 23 | 8.3 |
| | 1932 | 43.4 | 14.72 | 225 | 190 | 114 | 43 | 31 | 5.7 |
| | 1933 | 52.0 | 16.25 | 225 | 259 | 161 | 61 | 49 | 5.5 |
| | 1934 | 43.4 | 15.70 | 225 | 255 | 173 | 48 | 40 | 7.4 |
| | 1935 | 52.0 | 16.51 | 225 | 191 | 122 | 36 | 25 | 11.2 |
| Delaware | 1931 | 47.6 | 0.404 | 8.0 | 341 | 264 | 41.1 | | 15.1 |
| | 1932 | 46.4 | 0.380 | 8.0 | 341 | 248 | 29.0 | | 17.5 |
| | 1933 | 36.4 | 0.345 | 8.0 | 358 | 232 | 35.6 | | 18.3 |
| | 1934 | 51.1 | 0.354 | 8.0 | 386 | 274 | 33.0 | | 25.8 |
| | 1935 | 38.4 | 0.373 | 8.0 | 416 | 262 | 31.6 | | 26.4 |
| Fostoria | 1931 | 52 | 1.272 | 11.5 | 194 | 156 | 41.5 | 25.7 | 6.01 |
| | 1932 | 52 | 1.459 | 11.5 | 213 | 164 | 46.6 | 31.0 | 4.98 |
| | 1933 | 52 | 1.395 | 11.5 | 157 | 108 | 29.5 | 16.8 | 9.54 |
| | 1934 | 52 | 1.198 | 11.5 | 192 | 141 | 30.0 | 20.8 | 9.12 |
| | 1935 | 52 | 1.349 | 11.5 | 179 | 130 | 32.0 | 22.6 | 7.67 |
| Marion | 1931 | 42.9 | 1.456 | | 294 | 202 | 34.8 | 30.1 | 14.97 |
| | 1932 | 41.2 | 1.545 | | 262 | 185 | 33.3 | 30.4 | 14.53 |
| | 1933 | 40.2 | 1.530 | | 278 | 187 | 34.4 | 30.4 | 16.59 |
| | 1934 | 50.7 | 1.100 | | 381 | 272 | 50.7 | 45.1 | 20.24 |
| | 1935 | 43.7 | 1.211 | 23.25 | 365 | 246 | 42.7 | 37.9 | 18.76 |
| Norwalk | 1934 | 52 | 0.656 | 7.8 | 250 | 173 | 52 | 30 | 8.0 |
| | 1935 | 52 | 0.682 | 7.8 | 239 | 170 | 37 | 21 | 9.2 |

TABLE III.—*Trickling Filter Loadings and Performance at Ohio Sewage Treatment Plants 1931–1935*

| Location | Year | Filter Load Lbs./Day (a) | Filter Removal Lbs./Day (b) | Filter Eff. % | Filter Load Lbs./Day | | | Filter Removal Lbs./Day | | | Filter Load Per Acre Ft. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Per Acre Ft. | Per 1000 C.F. | Per Capita | Per Acre Ft. | Per 1000 C.F. | Per Capita | M.G.D. | Persons |
| Akron | 1931 | 25500 | 20630 | 80.9 | 182.2 | 4.18 | 0.142 | 147.2 | 3.38 | 0.115 | 0.200 | 1565 |
| | 1932 | 31450 | 24950 | 79.3 | 224.6 | 5.16 | 0.173 | 178.2 | 4.09 | 0.137 | 0.223 | 1720 |
| | 1933 | 27480 | 21200 | 77.2 | 196.3 | 4.51 | 0.147 | 151.5 | 3.48 | 0.114 | 0.224 | 1680 |
| | 1934 | 29300 | 23140 | 78.9 | 209.5 | 4.81 | 0.157 | 165.2 | 3.79 | 0.124 | 0.198 | 1485 |
| | 1935 | 29600 | 23060 | 77.9 | 211.5 | 4.85 | 0.153 | 164.9 | 3.78 | 0.119 | 0.212 | 1530 |
| Alliance | 1931 | 2275 | 1843 | 81.1 | 180.7 | 4.15 | 0.096 | 146.3 | 3.36 | 0.078 | 0.164 | 1870 |
| | 1932 | 2360 | 1935 | 82.0 | 187.4 | 4.31 | | 153.5 | 3.53 | | 0.150 | |
| | 1933 | 2200 | 1603 | 72.8 | 174.8 | 4.02 | | 127.0 | 2.92 | | 0.150 | |
| | 1934 | 2520 | 2018 | 80.0 | 200.0 | 4.59 | | 160.0 | 3.67 | | 0.145 | |
| | 1935 | 2106 | 1557 | 74.0 | 166.9 | 3.83 | 0.098 | 123.5 | 2.84 | 0.073 | 0.146 | 1700 |
| Canton | 1931 | 9790 | 7710 | 78.7 | 207.0 | 4.76 | 0.098 | 163.1 | 3.75 | 0.077 | 0.196 | 2120 |
| | 1932 | 9420 | 6790 | 72.2 | 199.1 | 4.58 | 0.091 | 143.8 | 3.30 | 0.066 | 0.216 | 2180 |
| | 1933 | 9960 | 7490 | 75.2 | 210.7 | 4.83 | 0.096 | 158.6 | 3.64 | 0.072 | 0.196 | 2200 |
| | 1934 | 10660 | 8230 | 77.2 | 225.4 | 5.17 | 0.102 | 174.1 | 4.00 | 0.079 | 0.199 | 2200 |
| | 1935 | 9660 | 7050 | 73.0 | 204.5 | 4.70 | 0.093 | 149.1 | 3.42 | 0.068 | 0.221 | 2200 |
| Cleveland, Southerly | 1931 | 9650 | 7100 | 73.6 | 160.8 | 3.69 | 0.074 | 118.3 | 2.72 | 0.055 | 0.182 | 2170 |
| | 1932 | 14000 | 8730 | 62.3 | 233.3 | 5.35 | 0.062 | 145.5 | 3.32 | 0.039 | 0.245 | 3750 |
| | 1933 | 21800 | 13540 | 62.2 | 363.0 | 8.33 | 0.097 | 226.0 | 5.18 | 0.060 | 0.271 | 3750 |
| | 1934 | 22600 | 16320 | 72.2 | 377.0 | 8.65 | 0.100 | 272.0 | 6.25 | 0.072 | 0.262 | 3750 |
| | 1935 | 16800 | 11850 | 70.5 | 280.0 | 6.43 | 0.075 | 197.5 | 4.53 | 0.053 | 0.275 | 3750 |

TABLE III.—*Continued*

| Location | Year | Filter Load Lbs./Day (a) | Filter Removal Lbs./Day (b) | Filter Eff. % | Filter Load Lbs./Day | | | Filter Removal Lbs./Day | | | Filter Load Per Acre Ft. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Per Acre Ft. | Per 1000 C.F. | Per Capita | Per Acre Ft. | Per 1000 C.F. | Per Capita | M.G.D. | Persons |
| Delaware | 1931 | 889 | 751 | 84.5 | 202.0 | 4.64 | 0.111 | 170.8 | 3.92 | 0.094 | 0.092 | 1820 |
| | 1932 | 785 | 693 | 88.3 | 178.5 | 4.10 | 0.098 | 157.5 | 3.62 | 0.087 | 0.086 | |
| | 1933 | 668 | 566 | 84.7 | 152.0 | 3.49 | 0.084 | 128.7 | 2.96 | 0.071 | 0.078 | |
| | 1934 | 808 | 711 | 87.9 | 183.8 | 4.22 | 0.101 | 161.6 | 3.71 | 0.089 | 0.081 | |
| | 1935 | 815 | 717 | 87.9 | 185.3 | 4.26 | 0.102 | 163.0 | 3.74 | 0.090 | 0.085 | |
| Fostoria | 1931 | 1654 | 1214 | 73.4 | 280.0 | 6.43 | 0.144 | 205.8 | 4.72 | 0.106 | 0.215 | 1950 |
| | 1932 | 1990 | 1424 | 71.6 | 337.0 | 7.74 | 0.173 | 241.0 | 5.43 | 0.124 | 0.247 | |
| | 1933 | 1256 | 913 | 72.7 | 212.6 | 4.88 | 0.109 | 154.7 | 3.55 | 0.079 | 0.236 | |
| | 1934 | 1408 | 1108 | 78.7 | 238.1 | 5.47 | 0.122 | 187.5 | 4.31 | 0.096 | 0.203 | |
| | 1935 | 1460 | 1101 | 75.4 | 247.0 | 5.67 | 0.127 | 186.3 | 4.28 | 0.096 | 0.228 | |
| Marion | 1931 | 2450 | 2028 | 82.8 | 175.0 | 4.02 | | 144.9 | 3.33 | | 0.104 | |
| | 1932 | 2380 | 1952 | 82.0 | 170.0 | 3.91 | | 139.5 | 3.21 | | 0.110 | |
| | 1933 | 2380 | 1942 | 81.6 | 170.0 | 3.91 | | 138.8 | 3.19 | | 0.109 | |
| | 1934 | 2492 | 2027 | 81.3 | 178.0 | 4.08 | | 144.8 | 3.33 | | 0.078 | |
| | 1935 | 2481 | 2050 | 82.5 | 177.5 | 4.08 | 0.107 | 146.5 | 3.37 | 0.088 | 0.087 | 1660 |
| Norwalk | 1934 | 945 | 661 | 70.0 | 300.0 | 6.89 | 0.121 | 209.8 | 4.82 | 0.085 | 0.208 | 2470 |
| | 1935 | 965 | 755 | 78.3 | 306.3 | 7.04 | 0.124 | 239.7 | 5.50 | 0.097 | 0.216 | 2470 |

(a) Based on 5 Day B.O.D. of applied sewage.
(b) Based on diff. of 5 Day B.O.D. of applied and filtered.

TABLE IV.—*Trickling Filter Efficiencies at Ohio Sewage Treatment Plants 1931–1935*

| Location | | % Efficiency Raw to Final | | Susp. Solids | | | 5 Day B.O.D. | | | Free Ammonia | | | Organic Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | P.P.M. | | % | P.P.M. | | % | P.P.M. N | | % | P.P.M. N | | % |
| | | Removal Susp. Solids | Reduct. 5 Day B.O.D. | Sett. | Filt. | Reduction | Sett. | Filt. | Reduction | Sett. | Filt. | Reduction | Sett. | Filt. | Reduction |
| Akron | 1931 | 86.3 | 89.5 | 116 | 82 | 29.3 | 109 | 20.8 | 80.9 | | | | | | |
| | 32 | 75.3 | 87.7 | 79 | 46 | 41.8 | 121 | 25.0 | 79.3 | | | | | | |
| | 33 | 81.4 | 88.9 | 99 | 73 | 27.1 | 105 | 24.0 | 77.2 | | | | | | |
| | 34 | 84.1 | 90.5 | 106 | 87 | 20.2 | 127 | 26.7 | 78.9 | | | | | | |
| | 35 | 78.2 | 89.2 | 121 | 104 | 20.6 | 120 | 26.5 | 77.9 | | | | | | |
| Alliance | 1931 | 87.4 | 91.5 | 67 | 32 | 52.3 | 132 | 25 | 81.1 | 20.22 | 3.96 | 80.4 | 11.12 | 5.35 | 51.8 |
| | 32 | 95.0 | 92.3 | 84 | 33 | 60.8 | 150 | 27 | 82.0 | 20.5 | 2.9 | 85.8 | 10.4 | 4.1 | 60.6 |
| | 33 | 90.8 | 88.9 | 79 | 54 | 31.7 | 140 | 38 | 72.8 | 20.7 | 3.7 | 82.1 | 10.4 | 5.8 | 44.2 |
| | 34 | 85.0 | 90.7 | 85 | 69 | 18.8 | 166 | 33 | 80.0 | 18.3 | 5.0 | 72.8 | 11.0 | 5.0 | 54.5 |
| | 35 | 84.7 | 87.5 | 73 | 65 | 11.0 | 138 | 36 | 74.0 | 16.7 | 4.7 | 71.9 | 9.5 | 5.4 | 43.2 |
| Canton | 1931 | 81.0* | 87.0 | 78 | 60 | 23.1 | 127 | 27 | 78.7 | | | | | | |
| | 32 | 75.8 | 83.6 | 63 | 65 | — | 111 | 31 | 72.2 | | | | | | |
| | 33 | 84.1 | 85.0 | 60 | 46.5 | 22.5 | 129 | 32 | 75.2 | | | | | | |
| | 34 | 81.2 | 87.6 | 75 | 57 | 24.0 | 136 | 31 | 77.2 | | | | | | |
| | 35 | 80.0 | 85.2 | 71 | 53 | 25.4 | 111 | 30 | 73.0 | | | | | | |
| Cleveland, Southerly | 1931 | 82.5 | 85.0 | 93 | 47 | 49.5 | 106 | 28 | 73.6 | 17.6 | 6.6 | 62.5 | 7.5 | 3.9 | 48.0 |
| | 32 | 82.0 | 72.8 | 105 | 67 | 36.2 | 114 | 43 | 62.3 | 19.2 | 8.6 | 55.2 | 8.7 | 7.7 | 11.5 |
| | 33 | 81.7 | 80.7 | 121 | 88 | 27.2 | 161 | 61 | 62.2 | 18 | 11 | 38.9 | 12 | 8.0 | 33.3 |
| | 34 | 81.2 | 84.3 | 110 | 85 | 22.7 | 173 | 48 | 72.3 | 15 | 10.4 | 30.7 | 11 | 7.9 | 28.2 |
| | 35 | 82.7 | 87.0 | 107 | 71 | 33.7 | 122 | 36 | 70.5 | 14 | 11 | 21.4 | 11 | 8.0 | 27.3 |

TABLE IV.—*Continued*

| Location | | % Efficiency Raw to Final | | Susp. Solids | | | 5 Day B.O.D. | | | Free Ammonia | | | Organic Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | P.P.M. | | | P.P.M. | | | P.P.M. N | | | P.P.M. N | | |
| | | Removal Susp. Solids | Reduct. 5 Day B.O.D. | Sett. | Filt. | % Reduction | Sett. | Filt. | % Reduction | Sett. | Filt. | % Reduction | Sett. | Filt. | % Reduction |
| Delaware | 1931 | 84.3* | 88.0 | 119 | 41 | 65.5 | 264 | 41.1 | 84.5 | | | | | | |
| | 32 | 88.0 | 91.4 | 112 | 31 | 72.3 | 248 | 29.0 | 88.3 | | | | | | |
| | 33 | 85.8 | 90.1 | 107 | 36 | 66.3 | 232 | 35.6 | 84.7 | | | | | | |
| | 34 | 90.8 | 91.5 | 102 | 30 | 70.5 | 274 | 33.0 | 87.9 | | | | | | |
| | 35 | 88.6 | 92.4 | 145 | 39 | 73.2 | 262 | 31.6 | 87.9 | | | | | | |
| Fostoria | 1931 | 86.0 | 86.7 | 129 | 66 | 48.8 | 156 | 41.5 | 73.4 | | | | | | |
| | 32 | 84.2 | 85.4 | 130 | 78 | 40.0 | 164 | 46.6 | 71.6 | | | | | | |
| | 33 | 85.7 | 89.3 | 116 | 77 | 33.6 | 108 | 29.5 | 72.7 | | | | | | |
| | 34 | 87.5 | 89.2 | 119 | 78 | 34.5 | 141 | 30 | 78.7 | | | | | | |
| | 35 | 85.6 | 87.4 | 128 | 88 | 31.2 | 130 | 32 | 75.4 | | | | | | |
| Marion | 1931 | 88.4 | 89.8 | 111 | 51 | 54.0 | 202 | 34.8 | 82.8 | 23.1 | 4.5 | 80.6 | 10.5 | 5.5 | 47.6 |
| | 32 | 89.2 | 88.5 | 94 | 41 | 56.3 | 185 | 33.3 | 82.0 | 23.4 | 5.0 | 78.5 | 10.0 | 4.7 | 53.0 |
| | 33 | 88.9 | 89.0 | 91 | 37 | 59.3 | 187 | 34.4 | 81.6 | 23.9 | 5.1 | 78.7 | 8.5 | 4.1 | 51.8 |
| | 34 | 88.4 | 88.1 | 115 | 47 | 59.2 | 272 | 50.7 | 81.3 | 34.1 | 9.2 | 73.0 | 10.8 | 5.0 | 53.7 |
| | 35 | 88.1 | 89.6 | 124 | 59 | 52.4 | 246 | 42.7 | 82.5 | 29.7 | 7.9 | 73.4 | 10.7 | 5.5 | 48.6 |
| Norwalk | 1934 | 84.5 | 88.0 | 74 | 104 | † | 173 | 52 | 70.0 | 17.4 | 5.3 | 69.6 | 9.5 | 8.8 † | 7.4 |
| | 35 | 88.6 | 91.2 | 67 | 69 | | 170 | 37 | 78.3 | 17.84 | 3.91 | 78.1 | 8.75 | 6.94 | 20.7 |

* No final sedimentation 1931–1935.
† Recirculation of filtered solids.

## Previously Recommended Loadings

At the Fifth Conference on Sewage Treatment, Mr. B. F. Hatch in his paper "Trickling Filter Loadings" tentatively recommended that a figure of 250 lb. 5-day B.O.D. of the applied sewage per acre foot (this corresponds to 5.74 lb./1000 cu. ft) be set as the probable upper limit of trickling filter loadings, for continuous production of a stable effluent. Also, an applied B.O.D. of less than 400 p.p.m. was recommended.

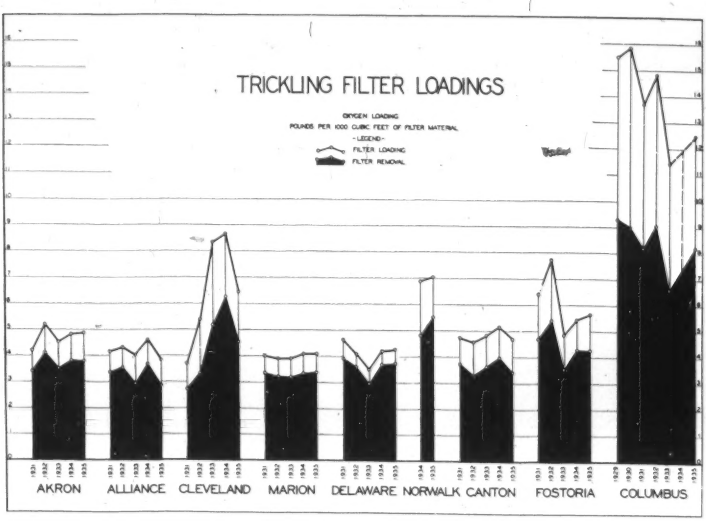
The operation data of the past five years substantiate these recommendations in so far as general operating conditions are concerned. In covering a limited range the results do not determine specifically the upper loading limit at which a stable effluent is produced. Carefully planned studies and tests at these plants covering a wider range of loadings both as to volume and strength would aid materially in trying to solve this problem, which contains so many variables.

## Variations in Oxygen Loading at Norwalk

To illustrate extreme loading and seasonal variations the filter performance at Norwalk is cited. There the sewage is applied upon three circular filters by revolving distributors. Table V includes the loadings and filter results covering days when strong industrial wastes were present in the sewage. It is of interest to note that during the months of April and May, 1934 (only the results for May are tabulated, for then the milk waste was constant, in April it was in slugs) loadings of 9 lb. B.O.D./1000 cu. ft. were applied, producing a filter effluent lacking in nitrites and nitrates and having a 5-day B.O.D. of 60 to 70 p.p.m. This unexpected industrial loading in the form of skimmed milk was later eliminated but while present it gave interesting data on loadings. In August and September in 1934–35–36 heavier industrial loads were encountered in the form of screened corn waste. Loadings increased to 14 lb./1000 cu. ft. and in some cases even higher. While such loads were variable in amount and strength they showed that under *ideal conditions* loadings up to 12 lb./1000 cu. ft have been treated for short periods producing an effluent having a 5-day B.O.D. from 30 to 40 p.p.m. with nitrites and nitrates from 2 to 3 p.p.m.

In studying these filter results at Norwalk it must be noted that the two industrial wastes differ as to type of oxidizable matter contained but the great difference in results was primarily seasonal. In other words, the biological life did not have the capacity for work in the spring that it had in the summer.

These results are presented to show the variation in filter effectiveness and not to recommend higher loadings. Such loadings over prolonged periods would be damaging to any sewage plant.


TRICKLING FILTER LOADINGS
OXYGEN LOADING
POUNDS PER 1000 CUBIC FEET OF FILTER MATERIAL
-LEGEND-
FILTER LOADING
FILTER REMOVAL
AKRON
ALLIANCE
CLEVELAND
MARION
DELAWARE
NORWALK
CANTON
FOSTORIA
COLUMBUS

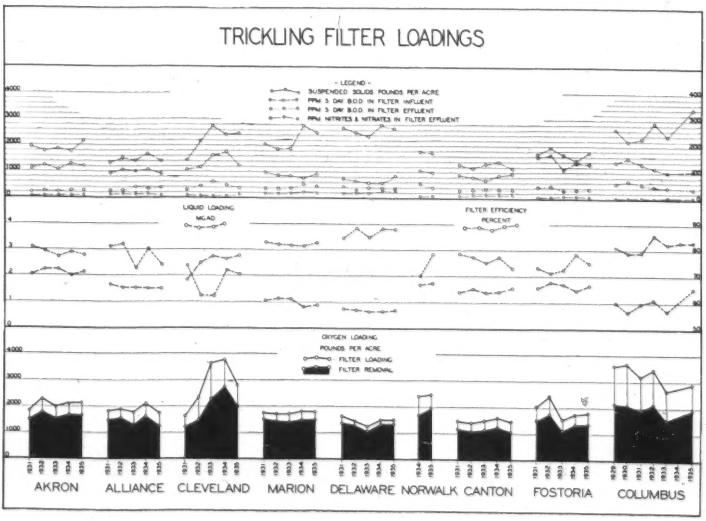

TRICKLING FILTER LOADINGS
-LEGEND-
SUSPENDED SOLIDS POUNDS PER ACRE
PPM 5 DAY B.O.D. IN FILTER INFLUENT
PPM 5 DAY B.O.D. IN FILTER EFFLUENT
PPM NITRITES & NITRATES IN FILTER EFFLUENT
LIQUID LOADING
MGAD
FILTER EFFICIENCY
PERCENT
OXYGEN LOADING
POUNDS PER ACRE
FILTER LOADING
FILTER REMOVAL
AKRON
ALLIANCE
CLEVELAND
MARION
DELAWARE
NORWALK
CANTON
FOSTORIA
COLUMBUS

TABLE V.—*Trickling Filter Loadings and Performance as Affected by Industrial Wastes at Norwalk*

| Date | | Flow in M.G.D. | 5 Day B.O.D. 20° C.—P.P.M. | | Nitrite and Nitrate P.P.M. N | Dissolved Oxygen at 10 A.M. | Filter Load Lbs./Day (*a*) | Filter Removal Lbs./Day (*b*) | Filter Eff. % | Filter Load Lbs./Day | | Filter Removal Lbs./Day | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sett. | Filt. | | | | | | Per Acre Ft. | Per 1000 C.F. | Per Acre Ft. | Per 1000 C.F. |
| May | 14 | 0.854 | 219 | 65 | 0.4 | 5.2 | 1560 | 1097 | 70.2 | 495 | 11.38 | 348 | 8.00 |
| 1934 | 15 | 0.639 | 206 | 54 | 0.7 | 5.6 | 1100 | 812 | 73.7 | 349 | 8.02 | 257 | 5.88 |
| | 16 | 0.632 | 235 | 64 | 0.0 | 5.7 | 1237 | 901 | 72.8 | 392 | 9.00 | 286 | 6.57 |
| | 17 | 0.631 | 245 | 81 | 0.0 | 2.7 | 1289 | 863 | 67.0 | 408 | 9.38 | 274 | 6.30 |
| | 18 | 0.636 | 217 | 87 | 0.0 | 0.9 | 1153 | 691 | 60.0 | 366 | 8.40 | 219 | 5.03 |
| Aug. | 17 | 0.619 | 196 | 20 | 7.7 | 4.7 | 1012 | 909 | 89.8 | 321 | 7.37 | 289 | 6.64 |
| 1934 | 19 | 0.485 | 198 | 21 | 4.4 | — | 800 | 715 | 89.4 | 254 | 5.83 | 227 | 5.22 |
| | 20 | 0.569 | 242 | 45 | 7.8 | 4.1 | 1149 | 936 | 81.5 | 365 | 8.38 | 297 | 6.82 |
| | 21 | 0.596 | 340 | 42 | 0.4 | 3.6 | 1690 | 1481 | 87.7 | 537 | 12.32 | 471 | 10.81 |
| | 22 | 0.559 | 340 | 54 | 0.3 | 2.3 | 1582 | 1331 | 84.2 | 503 | 11.57 | 423 | 9.72 |
| | 23 | 0.474 | 318 | 79 | 2.7 | 3.6 | 1260 | 947 | 75.2 | 400 | 9.20 | 302 | 6.94 |
| Sept. | 3 | 0.580 | 208 | 87 | 7.4 | — | 1008 | 586 | 58.1 | 320 | 7.35 | 186 | 4.28 |
| 1934 | 4 | 0.626 | 347+ | 54 | 3.3 | 4.3 | 1812+ | 1530 | 84.4 | 576+ | 13.21+ | 486 | 11.18 |
| | 5 | 0.610 | 342+ | 45 | 0.2 | 4.4 | 1740+ | 1511 | 86.8 | 553+ | 12.70+ | 480 | 11.02 |
| | 6 | 0.708 | 310 | 38 | 1.7 | 3.3 | 1835 | 1610 | 87.7 | 583 | 13.40 | 512 | 11.75 |
| Aug. | 18 | 0.615 | 344 | 19 | 1.6 | — | 1765 | 1668 | 94.5 | 560 | 12.87 | 529 | 12.16 |
| 1935 | 19 | 0.742 | 190 | 41 | 0.6 | 3.4 | 1175 | 921 | 78.3 | 373 | 8.57 | 292 | 6.72 |
| | 20 | 0.763 | 550 | 34 | 0.3 | 4.9 | 3500 | 3283 | 93.8 | 1111 | 25.58 | 1043 | 24.00 |

May '34—Skimmed Milk Waste in flow.
Aug. and Sept.—Screened Corn Waste in flow.

TABLE V.—*Continued*

| Date | | Flow in M.G.D. | 5 Day B.O.D. 20° C.—P.P.M. | | Nitrite and Nitrate P.P.M. N | Dissolved Oxygen at 10 A.M. | Filter Load Lbs./Day (*a*) | Filter Removal Lbs./Day (*b*) | Filter Eff. % | Filter Load Lbs./Day | | Filter Removal Lbs./Day | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sett. | Filt. | | | | | | Per Acre Ft. | Per 1000 C.F. | Per Acre Ft. | Per 1000 C.F. |
| | 21 | 0.706 | 320 | 27 | 0.8 | 4.6 | 1883 | 1724 | 91.6 | 598 | 13.75 | 547 | 12.56 |
| | 22 | 0.688 | 390 | 35 | 1.0 | 5.1 | 2240 | 2039 | 91.0 | 711 | 16.31 | 647 | 14.85 |
| | 23 | 0.693 | 400 | 33 | 0.6 | 4.5 | 2310 | 2119 | 91.7 | 733 | 16.83 | 672 | 15.42 |
| | 25 | 0.459 | 340 | 31 | 1.9 | — | 1300 | 1181 | 91.0 | 412 | 9.48 | 375 | 8.62 |
| | 26 | 0.646 | 400 | 42 | 0.7 | 4.1 | 2150 | 1924 | 89.5 | 682 | 15.65 | 611 | 14.02 |
| | 27 | 0.798 | 290 | 38 | 0.2 | 2.6 | 1930 | 1677 | 86.8 | 613 | 14.10 | 532 | 12.20 |
| | 28 | 0.702 | 320 | 41 | 0.0 | 3.6 | 1870 | 1630 | 87.2 | 593 | 13.61 | 517 | 12.88 |
| | 29 | 0.729 | 480 | 57 | 0.0 | 3.5 | 2920 | 2573 | 88.1 | 927 | 21.30 | 817 | 18.75 |
| | 30 | 0.756 | 390 | 59 | 0.0 | 2.5 | 2460 | 2088 | 85.0 | 781 | 17.92 | 663 | 15.22 |
| Aug. | 19 | 0.725 | 475 | 72 | 0.0 | 1.4 * | 2870 | 2434 | 84.8 | 912 | 20.92 | 772 | 17.71 |
| 1936 | 20 | 0.702 | 468 | 66 | 0.0 | 1.9 | 2740 | 2354 | 85.7 | 870 | 20.00 | 747 | 17.15 |
| | 21 | 0.909 | 400 | 66 | 0.0 | 1.8 | 3030 | 2530 | 83.7 | 962 | 22.10 | 803 | 18.45 |
| | 23 | 0.668 | 292 | 43 | 1.1 | — | 1627 | 1388 | 85.3 | 516 | 11.85 | 441 | 10.11 |
| | 24 | 0.772 | 336 | 41 | 1.4 | 2.4 | 2160 | 1896 | 87.3 | 586 | 13.47 | 602 | 13.81 |
| | 25 | 0.794 | 410 | 38 | 0.2 | 1.6 | 2720 | 2468 | 90.7 | 863 | 19.83 | 783 | 18.00 |
| | 26 | 0.662 | 320 | 49 | 2.2 | 2.3 | 1763 | 1493 | 84.7 | 560 | 12.88 | 474 | 10.90 |
| | 27 | 0.601 | 304 | 33 | 3.7 | 2.9 | 1522 | 1357 | 89.1 | 482 | 11.08 | 431 | 9.90 |

(*a*) Based on 5 Day B.O.D. of applied sewage. See Table V first part.
(*b*) Based on diff. of 5 Day B.O.D. of applied and filtered.
* All D.O. tests on filter effl. except during Aug. '36 when only final effl. tested.
Aug. and Sept.—Screened Corn Waste in flow.

## Expected Performance in Ohio

Under average operating conditions this study shows that where neither excessive oxygen loads nor gallonage figures result, trickling filters can be expected to produce results in Ohio as follows:

| | | |
|---|---|---|
| Reduction in 5-day B.O.D. | 70 to 90% | average 80% |
| " " Susp. Solids | 20 to 40% | average 33% |
| " " Free Ammonia | 40 to 90% | average 75% |
| " " Org. Nitrogen | 30 to 50% | average 45% |
| " " Alkalinity | 30 to 40% | average 35% |

Note: Results as determined from Settled to Filtered, i.e., final sedimentation not included.

## Summary and Conclusion

Trickling filters in Ohio have continuously produced a stable effluent in most cases when loadings have not exceeded those recommended by Mr. B. F. Hatch; namely, 250 lb. 5-day B.O.D. per acre foot, which is equivalent to 5.74 lb. per 1000 cu. ft.

The operation data at the several Ohio plants herein considered do not conclusively determine an upper limit of loading for desirable filter performance, as the loadings covered a limited range.

Strong industrial loadings have been treated at Norwalk. In the spring, with skimmed milk in the sewage, oxygen loading requirements of 9 lb./1000 cu. ft. were not satisfactorily treated as the resulting effluent contained, neither nitrites or nitrates and had a 5-day B.O.D. of 60 to 70 p.p.m. In August and September a screened corn waste increased loadings up to 12 lb./1000 cu. ft. and the effluent over short periods contained 2 to 3 p.p.m. of nitrates and had a 5-day B.O.D. of 30 to 40 p.p.m.

This investigation shows a need for further study to correlate operating loadings and design loadings.

## Discussion

By B. F. Hatch

*Assistant Engineer, Ohio Department of Health*

A paper of this type requires considerable time and effort in preparation and Mr. Hall is to be congratulated on the thorough manner in which the data are presented. A great deal of information is contained in the tables accompanying this paper, which is all the more worthwhile because the data represent performance under actual day-to-day operating conditions. When these data are expressed in graphical form some conclusions become self-evident and certain trends are indicated although by no means conclusively, chiefly because of the number of variables which cannot be eliminated.

In this paper it has been pointed out that the performance of a filter depends upon loading which in turn involves concentration and volume, and to these factors I would like to add oxidizability and contact. In the first of the two following charts the loading and removal

in terms of 5-day B.O.D. in pounds per 1000 cubic feet of filtering material is shown for each of the filters considered in this paper and also for the Columbus filter. The filters are grouped alphabetically according to depth beginning with the four 10-ft. filters and ending with the 5.25 ft. Columbus filter.

In studying this chart certain conclusions are self-evident. First, regardless of the amount of load, the B.O.D. removal curve follows the loading curve; that is, if the loading increases the B.O.D. removal increases and vice versa. Second, irrespective of the amount of load, the B.O.D. removed never equals the applied load. Third, as the applied load increases the amount of load contained in the filter effluent increases.

It is evident that oxidizability and contact play important parts in determining these characteristics. For a given rate of dosage per acre per day the contact period is longer in a deep filter than in a shallow one and therefore if other variables such as percentage and size of voids, method of dosage, filter cleanliness and oxidizability, are equal the deeper filter should produce a more completely oxidized effluent. Comparison of the Alliance and Canton filters, which receive sewages of about equal strength and at similar rates of application in m.g.a.d., indicates that the 10-ft. filter (Alliance) is but 3 per cent more efficient than the 7-ft. filter (Canton). On the other hand, the second chart indicates that the Cleveland filter (10 ft. depth) removes more B.O.D. in pounds per acre than the Columbus filter (5 ft. 4 in. depth). Hence the question as to the value of additional depth as against greater area cannot be determined from these data.

It is important to note that in Ohio, on account of the limited dilution available in our streams, we are more concerned with the pounds of oxygen demanding material remaining in a filter effluent than we are with filter efficiency in per cent. These data seem to indicate that when filter loadings exceed 5.6 lb. 5-day B.O.D. per 1000 cu. ft. of filtering material, effluents are likely to be produced which are not stable. When loadings exceed this figure, filters may still be operated as roughing filters to be followed by other methods of treatment or the loading may be reduced by more efficient removal of suspended solids than is obtained by plain sedimentation.

# OPERATION EXPERIENCES WITH CHLORINATION OF ACTIVATED SLUDGE *

By G. M. Ridenour, C. N. Henderson and H. B. Schulhoff

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Recent reports have drawn attention to the possible value of chlorine in the control of bulking difficulties in the activated sludge process of sewage treatment. The use of chlorine in the control of activated sludge bulking was brought up during earlier reports of Bell (1) in 1931 on the application of bleaching powder to the mixed liquor. However, at that time available data were not sufficient to determine the value of chlorine. Later investigations of Smith (2) and Smith and Purdy (3) dealt specifically with the use of chlorine in this connection and gave evidence that a bulking sludge could be controlled by the proper use of chlorine, applied either to the aeration tanks or in the return sludge prior to mixing with the sewage. The principal value was given to those cases of bulking caused by filamentous growths. Griffin (4) also transmitted a communication of Hodgson to the effect that the use of chlorine had been of value in a similar instance in Australia.

In view of these reports the writers thought it to be of interest to give results obtained by chlorination of activated sludge at the Marlboro Hospital Sewage Plant in New Jersey. The situation with respect to the character of sludge was very similar to that reported in the above studies and in general seemed to be equal to that required by the previous investigators for greatest benefits from the use of chlorine.

## Method of Investigation

The plant used for the study consisted of an activated sludge plant preceded by primary settling. Designed capacity of the plant was 1,300,000 gallons per 24 hours. Average aeration time during the study was approximately 18 hours on the basis of total daily flow or 12 hours on the basis of average day period rate of flow. The type of aeration during this period consisted of a combination of compressed air through porous tubes and mechanical surface aeration with brushes. Sludge return was accomplished by means of mechanical sludge collectors in the final settling tanks followed by air lifts to the sludge return channel.

Liquid chlorine was applied to the sludge return channel at the end of the channel farthest from the point of mixing with the settled sewage. The time of chlorine contact with the return sludge before mixing with settled sewage was approximately two minutes. The

* Jour. Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

Note. Part of the work was performed with the help of W.P.A. employees.

place selected for introducing the chlorine permitted intimate mixing of the chlorine with the return sludge by virtue of the turbulence of the air lift discharge.

Indices used during the study were selected to provide information as to the effect of the chlorine on, first, the settleability of the activated sludge floc, and second, the purification of the supernatant liquor. The tests for the former consisted of volume occupied by the activated sludge in a one-liter cylinder after 1 hour settling and the weight of suspended solids in the mixed liquor of the aerator. The sludge index of settling was obtained by the ratio of suspended solids in p.p.m. to the volume occupied in c.c. in a liter cylinder. The tests used as indices of purification were ammonia nitrogen, nitrate nitrogen, relative stability, turbidity and suspended solids in the effluent from the final clarifiers. The chlorine demand of the return sludge and the ash content of the activated solids were also recorded.

Microscopical examinations were made at regular intervals during the entire period to determine the relative abundance of filamentous organisms.

## Conditions of Activated Sludge Prior to Chlorination

Prior to the beginning of this study the activated sludge had developed into a light, slow settling and voluminous floc. The gradual development of this condition can be seen in the accompanying graph under the sludge settling index. Three months prior to chlorination, the floc had been dense and settled rapidly with a sludge index of 15. This was followed by a two month gradual decline to a sludge index of 2.0. Microscopical examinations showed the floc to consist almost entirely of fungus growths, particularly during the month preceding the chlorination test.

## Results

The chlorination results are given in the accompanying table and final part of the graph covering a period of chlorination of nearly two and one-half months. The results during the chlorination period are also related to similar indices at the plant for three and one-half months preceding the chlorination study, to serve for better comparison of the effect of chlorination.

An additional test made during the period of chlorination was the chlorine demand of the return sludge. Previous investigators (2) (3) have reported the chlorine dosages on the basis of p.p.m. or per cent per unit weight of solids. It is believed, however, that better comparison of dosages can be obtained on the basis of the per cent of total chlorine demand applied to the activated sludge mixture. Consequently, the results have been reported in relation to the chlorine demand, as well as on the basis of p.p.m. by volume of return sludge and per cent of weight on the dry solids basis. The chlorine dosage in this study covered a range from 3.1 to 72 per cent of the chlorine demand, which corresponded to a minimum of 2.0 p.p.m. and a maximum of 13.3

p.p.m. or from 0.01 per cent to 0.46 per cent chlorine on the dry solids basis. The highest dosage was carried for a period of approximately one-half month.

## Discussion

The results of this study, given in the accompanying table and graph show that chlorination of the activated sludge, within the ranges of chlorine dosages of from 3 to 72 per cent of the chlorine demand or 0.01 to 0.46 per cent on the dry solids basis, had no effect on the control of bulky sludge, either in reducing the numbers of filamentous organisms or in changing the settling character of the activated sludge floc. The settling index of the activated sludge floc remained almost constant during the entire period of chlorination under high and low chlorine dosages. The index was also practically unchanged from that existing for one and one-half months preceding chlorination.

With respect to the microscopical character of the floc, the records show that the sludge was uniformly high in filamentous fungi during the entire period, and very similar to the sludge during the period preceding chlorination after the slow settling floc had formed. Likewise, bacteria enclosed in zoogleal sacs, as well as protozoa, were very low in numbers. Though not recorded in the table, studies were also made after the methods of Henrici (5), (6), (7) by immersing glass slides in the liquid substrate at the inlet and outlet ends of the aeration tanks. The results of these studies showed no direct correlation between the microscopical character of the sludge floc and the film attaching itself to the glass slides. The film varied in microscopical character from week to week and gave no consistent trend. However, relatively speaking, the numbers of fungi attaching themselves to glass were found to be as great during the latter part of chlorination as during the beginning and before chlorination.

The attendant results also give evidence that the activated sludge floc, with respect to its sewage purifying ability, was not so sensitive to the action of chlorine as might be thought. During the period of chlorination, up to and including a chlorine dosage of 25 per cent of the chlorine demand of the sludge, the course of purification of sewage liquor remained practically the same as during the period preceding chlorination. Coincident with the increase of the chlorine dosage to 75 per cent of the sludge demand, the principal change in purification indices was measured in the increase in ammonia nitrogen and the decrease in the nitrate nitrogen in the plant effluent. This might logically be taken as an indication that the purification has been affected by the increased dose of chlorine at this point. However, it is to be noted that certain operation requirement demanded a reduction in the air supply to the aerators at approximately the same time these indices changed and the authors believe this change in operation procedure was more responsible for the reduced quality of the effluent, with respect to ammonia and nitrate indices, than the increase in chlorine. This seems to be substantiated by the fact that other indices of puri-

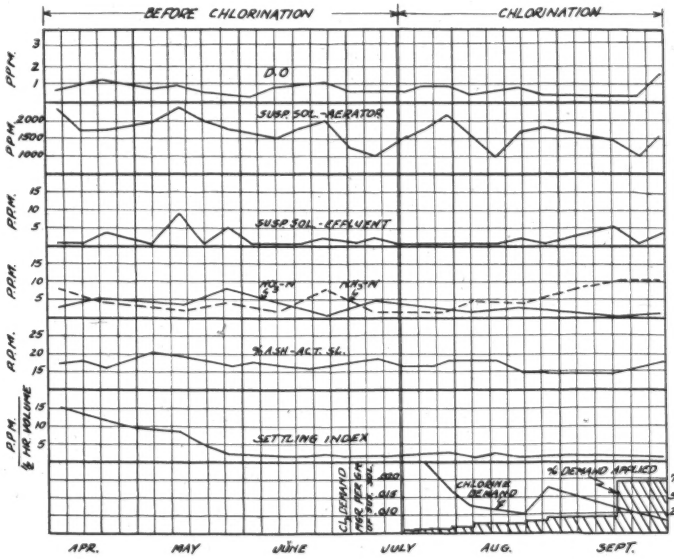
TABLE I.—*Results During Chlorination of Return Sludge*

| Date 1936 | Chlorination Data—Return Sludge | | | | | | Chemical Results | | | | | | Filamentous Organisms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lbs. per Day | p.p.m. | $Cl_2$ applied dry solids basis | $Cl_2$ demand per gm. Susp. Sol. | $Cl_2$ demand applied | Sludge* Settling Index | Susp. Sol. Eff. | $NH_3-N$ Eff. | $NO_3-N$ Eff. | D.O. Eff. | Susp. Sol. Aer. | Ash Aer. Solids | |
| | | | % | mgr. | % | | p.p.m. | p.p.m. | p.p.m. | p.p.m. | p.p.m. | % | |
| 7/15 | Chlorination of return sludge started | | | | | | | | | | | | |
| 7/15 | 0.33 | | .01 | | | 1.6 | 1 | | | 0.6 | 1470 | 16.9 | Most Predominant |
| 7/17 | 0.9 | | .03 | | | | | | | | | | |
| 7/20 | 1.5 | 2.0 | .08 | | 3.1 | | | | | | | | |
| 7/22 | 2.1 | 2.8 | .108 | .025 | 6.5 | 2.0 | 1 | 2.0 | 3.2 | 0.9 | 1766 | 16.9 | Most Predominant |
| 7/28 | 3.0 | 4.0 | .117 | | | | | | | | | | |
| 7/29 | 3.0 | 4.0 | .117 | .0168 | 12.3 | 2.4 | 1 | | | 0.9 | 2182 | 18.4 | |
| 8/5 | 3.0 | 4.0 | .117 | .0129 | 15.1 | 1.9 | 1 | 4.0 | 2.4 | 0.4 | 1556 | 15.3 | Most Predominant |
| 8/12 | 3.0 | 4.0 | .117 | | | 2.3 | 1 | | | | 990 | 18.6 | Most Predominant |
| 8/18 | 5.8 | 7.7 | .225 | | | | | | | | | | Most Predominant |
| 8/19 | 5.8 | 7.7 | .225 | .0100 | 17.0 | 1.9 | 2 | 4.0 | 3.2 | 0.8 | 1690 | 15.6 | |
| 8/26 | 5.8 | 7.7 | .225 | .0175 | 22.5 | 2.0 | 1 | | | 0.4 | 1832 | 15.5 | Most Predominant |
| 9/16 | 10.0 | 13.3 | .466 | .0132 | 72.0 | 1.6 | 5 | 10.0 | 0.32 | 0.3 | 1412 | 14.1 | |
| 9/29 | 10.0 | 13.3 | .466 | .0073 | 72.0 | 1.8 | 3 | 10.0 | 0.8 | 1.5 | 1576 | 17.3 | |
| 9/30 | Chlorination stopped | | | | | | | | | | | | |

* Wt. solids in p.p.m. / Liter Volume in c.c.—1 hr. settling

fication, not given in the data, such as relative stability and turbidity of the effluent, did not show a corresponding decrease in the quality of the plant effluent. Past performances at this plant also show that when the dissolved oxygen was lowered to the value noted above, a change in ammonia and nitrate nitrogen occurred to practically the same extent.

The difference in the results obtained at this plant as contrasted with those reported by others, even when chlorine dosages were used in amounts 400 per cent in excess of the amounts used by previous investigators (2, 3), might indicate that either (1) there is a vast difference in the resistance of the various fungi commonly associated with




sludge bulking, (2) the character and numbers of fungi were widely different or (3) there is such a wide difference in the chlorine consuming capacity of different sludges, that an extremely wide variation in the quantity of chlorine is required for effective results.

The relative resistance of the fungi is attested by their persistent growth, when started, in spite of all physical and chemical attempts toward their destruction, short of destroying the other organisms needed to carry on the purification process. That they are of varying resistance in different sewage is problematical, since the problem of sludge bulking due to these growths seems to be, at one time or another, of quite general experience. The relative difference in numbers would not seem to be of importance, since the varying quantities of chlorine used in this case covered a wide range and yet the abundance

of organisms was relatively unaffected. Differing results obtained by the use of chlorine might seem more logically explained on the basis of the varying chlorine demand of the activated sludge mixture.

Smith and Purdy did not report data on the per cent of chlorine demand applied and it may be that the difference of results, in what appear to be otherwise comparable conditions, may be explained on this basis, i.e. the chlorine dosages used by them on the basis of p.p.m. and per cent by solids weight, while smaller in quantity than those used in this study, were satisfying a larger percentage of the chlorine demand of the sludge. However, to be consistent with the results herewith obtained the dosages must have exceeded three-quarters of the total chlorine demand of the sludge mixtures.

This brings up the question whether a chlorine demand satisfaction higher than 70 per cent is not likely to be dangerous to the existence of other desirable organisms. The theory behind the effectiveness of chlorine on the control of sludge bulking necessarily depends on the selective action of chlorine on fungus growths such as *Cladothrix* and *Sphaerotilus* rather than on other forms of protozoal and bacterial life beneficial to purification. We have not been able to find experimental data which show greater sensitivity of the fungus forms of life causing bulking when present in sewage or activated sludge. On the other hand, Rudolfs and Ziemba (8) have shown that on sewage, a chlorine demand satisfaction of 60 per cent will cause a reduction in total organisms of 56 per cent in 2½ minutes and Rudolfs and Gehm (9) show reductions of 90 per cent in total bacteria after 10 minutes contact time.

An interesting complement of the chemical results is shown in the trend of chlorine demand of the activated sludge. This is shown in the lowest curve of the graph. The chlorine demand decreased from a maximum at the commencement to a minimum at the end of the chlorination period. The break in the consistent downward trend can possibly be explained on the basis of difference in oxygen content in the aerators. It is noticeable that this temporary readjustment in the level of the chlorine demand was coincident with the lower level of residual dissolved oxygen in the aerators as shown by the top curve in the graph. It would seem to appear from these data that the continuous application of chlorine, although in amounts considerably less than the demand of the sludge, has a "cumulative" effect in the reduction of chlorine-consuming material. It might be assumed that chlorination would not be effective until a definite chlorine demand of all the sludge was satisfied, which due to the retaining capacity of the aerators would require a considerable time before the effect was felt on the bulking sludge. In this case, however, the displacement of all the sludge required about 12 days, which was considerably shorter than the entire period of chlorination.

## Summary and Conclusions

Studies were conducted at the Marlboro activated sludge plant in New Jersey on the use of chlorine in the control of a bulky sludge.

The method of study consisted of chlorinating the return sludge in amounts up to 72 per cent of the chlorine demand or 0.46 per cent on the dry solids basis. Information was secured as to the effect of chlorine on (1) the purification of the sewage (2) settleability of the activated sludge floc, and (3) filamentous organisms.

Under the conditions existing at this plant the following results were obtained:

(1) Chlorine applied to the return sludge in amounts as high as 72 per cent of the chlorine demand, or 0.46 per cent on the dry solids basis had no effect toward increasing the sludge settling index.

(2) The filamentous character of the sludge remained unchanged as far as could be observed from microscopical examinations.

(3) Purification of the sewage liquor was practically unaffected by the chlorine.

(4) The chlorine demand of the sludge decreased during the period of chlorination from a maximum amount at the beginning to a minimum at the end of chlorination.

## References

1. Bell, *Proc. Assoc. Mgr's Sewage Disposal Works*, **27** (1931).
2. Smith, *Water Works & Sewerage*, **82** (1935).
3. Smith and Purdy, *This Journal*, **8**, 223–30 (1936).
4. Griffin, *21st Meeting N. J. Sew. Wks. Assoc.*, **69** (1936).
5. Henrici, *Jr. Bact.* **25**, 3 (1933).
6. Henrici, *Jr. Bact.* **30**, 1 (1935).
7. Henrici, *Jr. Bact.* **32**, 3 (1936).
8. Rudolfs and Ziemba, *Jr. Bact.* **28**, 4 (1933).
9. Rudolfs and Gehm, *N. J. Agr. Expt. Sta. Bul.* **601** (1936).

# SEWAGE PLANT CONSTRUCTION WITH W.P.A. LABOR*

By M. W. Tatlock

*Supt. Sewage Treatment, Dayton, Ohio*

The present Dayton sewage treatment plant was designed by Metcalf and Eddy, Engineers, Boston, Mass. In their "Memoranda Regarding Sewage Disposal Investigation of 1923" their selection of plain sedimentation, as the type of treatment for Dayton sewage, was based on the following standard of cleanliness for the Miami River, at and below Dayton:

1. The stream should be maintained in such a condition as to obviate the production of disagreeable odors either from the waters of the stream itself or from putrefying sludge deposits.
2. Floating sewage matters such as garbage, match sticks, paper, etc., should not generally be present on the surface of the stream.
3. The stream should generally be practically free from floating scum, unsightly foam and sludge.
4. The stream should generally be practically free from oil sleek.
5. The discharge of wastes and sewage into the stream should not produce an excessive discoloration of the river waters.
6. Extensive deposits of septic sludge should be prevented.
7. Uniform mixture of the sewage or the sewage effluents with the stream waters within a reasonable distance of the point of discharge of such sewage or effluents should be secured.

## Stream Flow and Dissolved Oxygen

An examination of all available records on stream flow for 32 years, 1893 to 1924, showed that there had been but one month having an average flow of less than 350 c.f.s. This flow was, therefore, adopted as the minimum which might be expected and it was used in the calculation of the oxygen available to meet the demands of the treated sewage.

The engineers made an extensive survey of the river and reported that "although it is impossible to predict with exactitude the minimum dissolved oxygen content which will occur at times of low flow, *it seems reasonable to expect* that the dissolved oxygen content will not drop below 7.0 p.p.m., which is 0.66 p.p.m. less than the average found in our investigations." This survey also indicated that the 1-day oxygen demand of the stream would be 1 p.p.m. and they assumed that 1.5 p.p.m. should be the minimum to which the dissolved oxygen content of the river could be reduced and yet remain inoffensive and provide enough oxygen to support fish life. These allowances indicated that the dissolved oxygen available for the satisfaction of the 1-day oxygen

* Presented before the Ninth Annual Meeting of the Central States Sewage Works Association, Indianapolis, Ind., Oct. 30, 1936.

demand of the Dayton sewage at times of extreme low flow was 4.5 p.p.m.

Using these allowances, Fig. 1 was prepared to show the diluting water required to maintain 1.5 p.p.m. of dissolved oxygen in the stream below the plant with different degrees of sewage treatment. It clearly indicated that with the minimum flow of 350 c.f.s., Imhoff tank treatment or its equivalent would suffice until 1937 and thereafter further treatment by trickling filters or activated sludge would be required, but to insure some factor of safety, 1935 was selected as the date when further treatment could be expected to be required.

The plans for the present plant were drawn up on the basis of these investigations, but when they were approved by the State Department

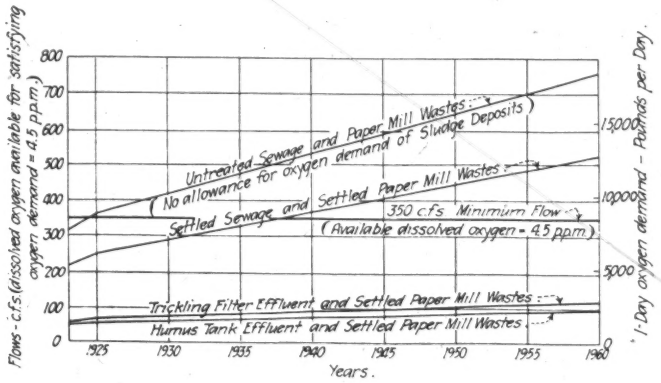



FIG. 1.—Dayton, Ohio.

Diluting water required to maintain not less than 1.5 P.P.M. of dissolved oxygen at West Carrollton Dam and degree of sewage treatment needed at times of minimum river flow under present and future conditions.

of Health (June 27, 1927), one of the conditions attached to the approval read as follows:

"2nd. That the date set forth as the time for consideration of additional treatment of sewage, namely 1935, is not accepted by the Director of Health, but rather that this shall be made the subject of study by observation of actual conditions after the plant has been constructed and operation commenced; and, therefore, that when deemed necessary by the Director of Health, additional devices for the treatment of the sewage shall be provided."

These basic design facts and terms of approval by the Department of Health clearly indicated that careful observations of all plant operation and stream conditions should be made. These observations are recorded in the following data tables.

Table I shows a comparison between the actual and expected loadings and removals by the Imhoff Tanks:

TABLE I.—*Comparison of Actual and Expected Loadings and Removals by Imhoff Tanks * at Dayton*

| | Estimated 1935 | Actual 1930* | 1931 | 1932 | 1933 | 1934 | 4 Yr. Average* |
|---|---|---|---|---|---|---|---|
| Population | 262,000 | 218,081 | 221,081 | 224,081 | 227,081 | 230,081 | |
| Sewage Flow M.G.D. | 26.2 | 18.4 | 21.4 | 22.0 | 21.7 | 19.4 | 21.1 |
| Sewage | | | | | | | |
| Suspended Solids | | | | | | | |
| P.P.M. | 170 | 218 | 221 | 214 | 215 | 271 | 230 |
| Lbs. per day | 37,000 | 33,400 | 39,200 | 39,200 | 38,900 | 43,700 | 40,500 |
| *Effluent* | | | | | | | |
| Suspended Solids | | | | | | | |
| P.P.M. | 85 | 110 | 93 | 109 | 97 | 113 | 103 |
| Lbs. per Day | 18,500 | 16,700 | 16,300 | 20,000 | 17,500 | 18,250 | 18,100 |
| *Per Cent Reduction* | 50 | 49.5 | 58 | 49 | 55 | 58 | 55 |
| *Deposited Solids* | | | | | | | |
| P.P.M. | 85 | 108 | 128 | 105 | 118 | 158 | 127 |
| Lbs. per Day | 18,500 | 16,700 | 22,700 | 19,200 | 21,400 | 25,600 | 22,400 |
| *Sewage* | | | | | | | |
| 5-Day B.O.D. | | | | | | | |
| P.P.M. | 160 | 193 | 198 | 181 | 141 | 182 | 175 |
| Lbs. per Day | 34,900 | 29,600 | 35,200 | 33,200 | 25,500 | 29,400 | 30,800 |
| *Effluent* | | | | | | | |
| 5-Day B.O.D. | | | | | | | |
| P.P.M. | 112 | 124 | 101 | 101 | 68 | 91 | 90 |
| Lbs. per Day | 24,400 | 18,900 | 18,000 | 18,500 | 12,300 | 14,750 | 15,850 |
| *Per Cent Reduction* | 30 | 36 | 49 | 44 | 52 | 50 | 49 |

* 1930 results are not included in the averages because of the excess foaming during the early months of the first year's operation.

Table II shows the stream flows since the plant went into operation.

TABLE II.—*Stream Flows*

Cu. Ft. per Second

| Period* | 1930 | 1931 | 1932 | 1933 | 1934 |
|---|---|---|---|---|---|
| 1 | 13,792 | 435 | 7,520 | 5,410 | 935 |
| 2 | 5,876 | 550 | 3,240 | 1,850 | 369 |
| 3 | 3,077 | 890 | 1,952 | 5,650 | 1,321 |
| 4 | 1,619 | 2,155 | 1,780 | 6,320 | 1,935 |
| 5 | 804 | 1,105 | 785 | 10,230 | 460 |
| 6 | 693 | 427 | 455 | 2,070 | 352 |
| 7 | 492 | 514 | 1,627 | 880 | 458 |
| 8 | 313 | 921 | 324 | 613 | 236 |
| 9 | 453 | 714 | 165 | 595 | 499 |
| 10 | 426 | 520 | 265 | 1,480 | 365 |
| 11 | 400 | 480 | 443 | 542 | 288 |
| 12 | 423 | 806 | 1,695 | 543 | 264 |
| 13 | | 4,090 | 2,820 | 1,078 | 294 |

* Beginning 1931 all plant records are based on a 13-period calendar instead of the regular 12 months calendar.

The underlined average figures indicate the flows which are equal to or less than the estimated monthly minimum average flow.

Table III shows the dissolved oxygen content and Table IV shows the 5-day B.O.D. during the periods of low stream flow in 1934.

TABLE III.—*Stream Conditions. Low Water Stages, 1934. Dissolved Oxygen*

| Period | Flow C.F.S.* | Dissolved Oxygen, P.P.M. | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Stations | | | | | | Avg. |
| | | A | B | C | D | E | F | |
| 6 | 352 | 5.5 | 3.6 | 0.8 | 0.8 | 1.3 | 3.2 | |
| 7 | 407 | 3.4 | 3.5 | 1.5 | 2.1 | 1.4 | 2.1 | |
| 8 | 217 | 2.3 | 3.2 | 0.0 | 0.9 | 0.7 | 1.9 | |
| 9 | 343 | 1.2 | 3.7 | 1.9 | 1.2 | 1.4 | 2.5 | |
| 10 | 341 | 4.0 | | | 1.3 | | 1.6 | |
| 11 | 288 | 4.2 | 3.7 | 0.6 | 0.6 | 0.6 | 1.0 | |
| Avg. | 325 | 3.5 | 3.5 | 1.0 | 1.1 | 1.1 | 2.0 | 1.7 |
| 12 | 264 | 8.5 | | | 4.3 | | 2.4 | 4.1 |
| 13 | 294 | 5.8 | | | 5.1 | | 4.5 | |
| Grand Avg. | 313 | 4.4 | 3.5 | 1.0 | 2.0 | 1.1 | 2.4 | |

TABLE IV.—*5-Day B.O.D.*

| Period | Flow C.F.S.* | 5-Day B.O.D., P.P.M. | | | | | |
|---|---|---|---|---|---|---|---|
| | | Stations | | | | | |
| | | A | B | C | D | E | F |
| 6 | 352 | 5.6 | 18.7 | 10.1 | 10.8 | 7.8 | 8.4 |
| 7 | 407 | 4.9 | 19.0 | 6.0 | 5.4 | 6.2 | 7.1 |
| 8 | 217 | 12.7 | 24.0 | 8.0 | 19.2 | 1.6 | 16.0 |
| 9 | 343 | 9.2 | 30.0 | 5.2 | 9.2 | 8.4 | 13.0 |
| 10 | 341 | 1.2 | | | 7.9 | | 7.3 |
| 11 | 288 | 2.1 | 2.4 | 6.7 | 10.6 | 5.0 | 4.7 |
| Avg. | 325 | 5.9 | 18.8 | 7.2 | 10.5 | 5.8 | 9.4 |
| 12 | 264 | 3.8 | | | 15.5 | | 6.6 |
| 13 | 294 | 3.3 | | | 10.5 | | 7.3 |
| Grand Avg. | 313 | 5.3 | | | 11.1 | | 8.8 |

* In these tables the stream flows are not identical with those in the table giving monthly avg. flows for each year since the plant has been in operation. The flows used in this table are the avg. monthly flows, omitting the temporary rises caused by a local rain occurring at such times that the rise had no connection with the analytical data.

These data indicated that while the engineers estimated the Dayton sewage in 1935 should carry 37,000 lb. suspended solids and 34,900 lb. 5-day B.O.D. per day, it actually carried on an average for the four

years prior to this date, 40,500 lb. suspended solids and 30,800 lb. 5-day B.O.D. per day. The engineers also estimated that the receiving stream would never fall below a minimum average monthly flow of 350 c.f.s., carrying a minimum available dissolved oxygen content of 4.5 p.p.m. or 8500 lb. daily. But for six months of 1934 the average monthly flow of the river was 325 c.f.s., carrying an average dissolved oxygen content of only 1.7 p.p.m., or 2980 lb. daily, while during this time the 1-day B.O.D. of the Dayton sewage was 4560 lb. per day.

These facts made it clearly evident that additional treatment of the sewage was necessary to prevent gross pollution of the Miami River, with its attendant health hazards and property damages, before complaints were filed against the city. Preliminary studies were, therefore, begun as early as Sept. 1, 1934, on the cost of secondary treatment for Dayton sewage and a preliminary report was made to W. W. Morehouse, Director of the Dept. of Water, Jan. 19, 1935, setting forth the results of these preliminary studies; and a final report was filed April 22, 1935. A letter was also received by the Hon. F. O. Eichelberger, City Manager, Feb. 15, 1935, from Mr. F. H. Waring, Chief Engineer, The State Department of Health, which stated, "You will recall that assistant engineers of this department have from time to time visited the Dayton plant, checked its operation and observed the stream conditions. During the past year these stream conditions point decidedly to the necessity for further treatment of the Dayton sewage before disposal of the effluent in the Miami River if proper cleanliness is to be obtained in this stream and a nuisance as a result of Dayton sewage prevented.

"It is the judgment of this department that these additional devices should now be constructed as promptly as possible."

## Report Recommendations

The reports stated that there were two recognized processes of secondary treatment, both biologic in character; activated sludge treatment or trickling filters, each of which is followed by final removal of the resulting sludge; and that there was also some agitation, just at that time, favoring treatment by chemical precipitation and flocculation methods. Each method of treatment was discussed in detail and the final recommendation was based on two considerations; first, would the process produce the desired degree of purification, and second, could it be financed, both as to construction and operation, without increasing the present sewer service charges.

*Chemical Precipitation.*—Progress in the treatment of sewage has been marked by the recurrence of cycles in which emphasis has been placed either on the biologic or chemical phases. The first chemical coagulation cycle flourished in the United States in the decade from 1890 to 1900, but waned thereafter and fell into almost complete disuse. The widespread introduction of mechanical equipment into sewage treatment practice, together with the promotion of the sales of chemicals has renewed interest in the process." This new interest is so

recent and the proven advances are so meager that it is impossible to decide what permanent contribution to the treatment of sewage will result from the present agitation and one can only question the outcome of all the experimental and promotional activity now under way."

A study of the results of most of these processes reveals that the degree of purification attainable by chemicals alone lies between that obtainable by plain sedimentation and that obtainable by biologic processes. Only by the addition of additional treatment, perhaps trickling filters and sedimentation, can an effluent be produced, comparable to that produced by either biologic process. The best available figures indicate that for this type of treatment, the chemicals alone will cost $8.00 per million gallons plus some additional labor and power. This cannot be financed by the present sewer service charge.

*Activated Sludge Process.*—The purification effected by this process is high; a 95 per cent removal of B.O.D. and suspended solids may be expected with well controlled operations; this degree of treatment will meet all demands as to the quality of the effluent. The construction cost is lower than for trickling filters but a greater part of the cost is for equipment. The operation cost may be expected to be higher than that estimated for chemical treatment. The process has not been considered because it cannot be operated on the present sewer service charge.

*Trickling Filters.*—This type of treatment, like the activated sludge treatment, will produce a stable effluent but it will not remove quite as high percentage of suspended solids and B.O.D.; however, the quality of the effluent will meet all the requirements for maintaining the purity of the receiving stream. From the standpoint of constant performance without such close supervision, trickling filters are preferable to the activated sludge process. Trickling filters can be operated without any increase in the present sewer service charge and they will produce the degree of purification required; they are, therefore, recommended for construction if some plan for financing the construction can be arranged.

## The Proposed Plant

The plant has been designed as 20 filters, each 165 ft. in diameter and 7½ ft. average depth; this provides 32,070,000 cu. ft. of filter stone against the actual requirements of 31,900,000.

There are 4 final settling tanks for the filter effluent, each 80 ft. in diameter and 9 ft. deep at the side walls, providing 1½ hrs. detention at the average rate and 1 hr. detention at the maximum rate. These tanks will have peripheral weirs and will be equipped with mechanical cleaners for the removal of sludge. A pump house is provided to house the pumps for sludge pumping. The piping will be so arranged that this sludge may be returned either to the influent conduits of the Imhoff tanks, to the separate sludge digestion tanks, or to the sludge drying beds.

The influent conduit to the filters will be provided with a ¼ in. mesh screen for removal of coarse debris. The filters will be equipped with

valves on both the inlets and outlets so that they may be completely flooded for filter fly control. Ample underdrains and ventilation system are provided. A bypass is provided for the final settling tanks.

The influent conduits to the filters have been designed of sufficient size to carry the flows for the future extensions necessary to serve the growth of the city, and the main effluent collector is large enough to carry the effluent from the future extensions to 1970.

These plans were approved by the State Department of Health and estimates of cost were set up. These estimates indicated very clearly that the project could not go forward without federal aid to a very substantial extent. An Ohio Supreme Court ruling had made the issue of bonds dependent on a 65 per cent vote of the people and they have not yet returned to a bond approving mood. This situation apparently removed P.W.A. from the picture, so we turned to the W.P.A., but this Administration had a ruling which removed any project costing more than $25,000 from their jurisdiction, unless it had first been refused by the P.W.A., so it became necessary to prepare and submit the project to the P.W.A. and convince them that the City of Dayton could not finance it. The project was rejected by the P.W.A. and re-submitted to the W.P.A. on July 5, 1935. It was passed by the local district office, by the state office and passed on to Washington. After much correspondence, trips to the state office at Columbus, and one trip to Washington, the project received presidential approval for operation, just as it was set up. This called for a federal expenditure of $663,848 and a sponsor's contribution of $218,015, totaling $881,863. A change in labor rates to conform to local wage scales later increased the federal funds to $730,232 and the sponsor's share to $246,484, making the total estimated cost $976,716.

The federal funds included all labor and trucks, operating superintendence, all forms, reinforcing steel, cement, cast iron and precast concrete pipe, wrought iron pipe, all valves and sluice gates, nails, form-ties, pipe joint materials and one-third of the filter materials. The sponsor's contribution was to cover the cost of preparation of plans, field engineering and inspection, sand and gravel in the ground (to be excavated, screened and washed by the W.P.A. labor), and all the special equipment for the project; i.e., the dosing siphons, the rotary distributors, the final tank clarifiers, the digester covers, the heating equipment, and the sludge pumps. It was expected that the other two-thirds of the filter material would be quarried on city property, crushed and hauled to the plant site. The value of the material in the ground, the sand and gravel and filter stone, was a considerable portion of the sponsor's contribution which did not represent a cash expenditure. The Department of Water owned two one-yard Northwest shovels which were to be furnished for the excavation and handling of materials. The concrete mixers and gravel washing and screening plant were also sponsor's contributions. The fair rental value of this equipment also became a substantial contribution without the equivalent cash expenditure.

In planning the whole project everything was done to produce labor hours. The reinforcing steel was all fabricated on the job. The under-drainage and ventilation system was worked out as pre-cast concrete instead of purchasing a manufactured product.

## Size of Project

Some idea of the magnitude of the project is reflected in these principal items:

| | | |
|---|---|---|
| Excavation | 250,000 | yd. |
| Backfill | 98,000 | yd. |
| Forms | 1,936,834 | sq. ft. |
| Reinforcing Steel | 528 | tons |
| Reinforcing Mesh | 104 | tons |
| Concrete | 19,882 | yd. |
| Cast Iron Pipe | 156 | tons |
| Filter Materials | 120,000 | yd. |

## Progress of Project

Actual construction began Jan. 28, 1936. The excavation is completed and 19,000 cu. yd. concrete had been poured to Dec. 31, 1936, which indicates the proportional tonnage of reinforcing steel that has been placed and the number of square feet of forms that have been built. The excavation has cost $1.075 per cu. yd., the forms 7.05 cents per sq. ft., the reinforcing steel, unloaded, fabricated, hauled and placed, $98.00 per ton, and the concrete $10.80 per cu. yd. In terms of units, the following work is completed: all the connecting conduits; 20 filters (Fig. 2 and Fig. 3) excepting the floor slabs in one-half unit and the

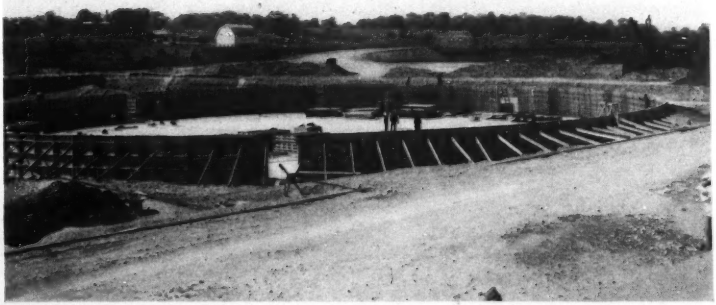


Fig. 2.—Shows forms being set up for the first filter wall. The outside forms are about complete, the inside forms are about half complete and the reinforcing is shown. May 15, 1936.

underdrainage in five; the 4 final settling tanks, excepting the floors and collection troughs; the two digestion tanks and 1450 ft. of 6 ft. section storm sewer through the plant site. The work has been carried forward under this federal aid program as if the W.P.A. were the contractor and the City of Dayton the owner, represented by the writer as resident engineer, who has written all the specifications for all federal purchased materials, and has been given complete co-operation by both the district and state material specifications and procurement divisions in obtaining the exact materials specified.

The filtering material and the special equipment, except the floating covers for the digesters, have not yet been purchased. The filter material will all be slag where it was originally intended to make the bot-

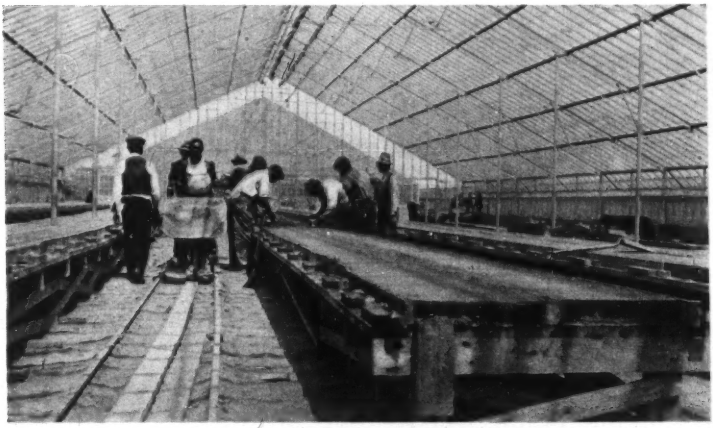


FIG. 3. Precast concrete crew making filter blocks for the filter underdrainage. This job required 800,000 blocks 2 ins. by 3⅝ ins. by 21 ins. May 1, 1936.

tom two-thirds stone and the top third slag. The stone from the city quarry failed to meet the 20-cycle sodium sulphate test for soundness and no known stone is available near Dayton which will meet this test. Slag is available at Hamilton at a price which almost eliminates stone from consideration. The equipment specifications will soon be completed and advertised for bids by the purchasing agent of the City of Dayton.

The project is now near enough to completion that the citizens of Dayton look forward to a complete treatment plant which will compare most favorably with anything of its kind in the United States, and for size, it will be the largest rotary distributor installation built to date. The project became a possibility because of the W.P.A. program and a reality because the Ohio Sewer Rental Law made it possible to build up a surplus revenue fund which may be used to enlarge ex-

isting treatment works. The Dayton Ordinance established a rate which has been adequate to finance maintenance and operation costs and still leave a small surplus to accumulate each year. This accumulated surplus and the W.P.A. have made the project a nearly completed reality.

The problems arising under this works program have required patience and understanding, to say nothing of perseverance and tenacity of purpose. Through the work to date, the writer wishes to take this public opportunity to express his personal appreciation and for the City of Dayton, to all the W.P.A. officials with whom he has worked to make this project a monument in concrete and stone, to a program touching so closely the lives of so many individuals. This would never have been possible without the closest cooperation between the state office, the district office, the supervising field engineers and the project superintendent. The experience has been an education, a lot of hard work, a study in group psychology, likely never to be forgotten, but hoped never to be experienced again.

# THE GENEVA N. Y. SEWAGE TREATMENT PLANT*

By E. A. Marshall

*Plant Superintendent, Geneva, N. Y.*

Until a year ago, the city of Geneva, N. Y., discharged its sewage wastes through three submerged outlets into Seneca Lake without treatment. Seneca Lake, one of the beautiful Finger Lakes, is a large deep body of water with a tributary drainage area of over 700 square miles. While the volume of fresh clean diluting water flowing through the lake was many times the volume of sewage discharged into it, and offered large capacity for natural purification, local nuisances occurred at the points of discharge and under certain conditions of wind and lake currents, polluted water might be carried back to the water supply intake. Popular bathing beaches are located at and near the outlet of the lake. The most important sewage outfalls were about two miles above the beaches and conditions were aesthetically objectionable if not actually dangerous.

The sewage system is of the separate type with, however, substantial storm water infiltration after heavy rainfalls. During the canning season, an unusually heavy organic load is present due to factory wastes.

After a study of the sewerage system and the degree of purification required it was decided to install primary treatment of the separate sludge digestion type, providing clarification plus chlorination of the sewage. Owing to the layout of the sewer system and economic considerations, it was desirable to construct two separate plants. The main plant, known as the Gulvin Park Plant, which has been in operation for a year, receives about 90 per cent of the sewage flow. Sewage from the extreme southerly end of Geneva will be treated at the small Mile Point Plant, now under construction.

## Description of Plant

The Gulvin Park Plant is designed for an average flow of 3.38 million gallons per day from a population of 22,500. It consists of a screen chamber, pumping station, three sedimentation tanks, two sludge digestion tanks, two sludge drying beds, and duplicate automatic chlorinating equipment. Sludge gas is collected and utilized for heating sludge and the pumping station building.

Sewage is brought to the site through two trunk sewers. From the junction of these sewers, it is conveyed through a short stretch of 30 in. cast iron pipe to a by-pass manhole and to the screen chamber. The by-pass, which is sealed, was used during construction of the plant and is available now for emergency use.

Two screens are provided. One is a Jeffrey mechanically cleaned screen with grit sump. The screen consists of ⅜ by 2 in. wrought steel

* Presented at the Fall Meeting of the New York State Sewage Works Association, Geneva, New York, October 9–10, 1936.

bars with 1 in. clear spacing, 4 ft. wide and with a normal capacity of 6 million gallons per day. The second screen is manually cleaned and consists of ½ by 3 in. bars, with 1 in. clear spacing, 4 ft. wide. It is provided for emergency use and comes into operation when the sewage level ahead of the screens rises a certain distance above normal level.

After passing the screens, sewage enters a 30,000 gallon suction well which serves to balance sewage flows and equalize pumping operations.

The pumping equipment consists of three Chicago motor-driven vertical centrifugal pumps, float-controlled, with capacities of 3.0, 4.0 and 5.0 million gallons per day respectively. The pumps are located in the head house basement with the motors mounted above on the first floor. A Venturi meter tube is located in the 20 in. pump discharge line within the building. Duplicate Wallace and Tiernan solution-feed chlorinators, with proportional feed controlled by the Venturi meter, are located on the first floor of the head house. Mono-rail system for handling and provision for storing one ton chlorine cylinders are provided. Primary chlorine is applied to the discharge line within the basement and immediately beyond the Venturi tube. The force main from the building to the sedimentation tanks is a 20 in. cast iron line.

The three reinforced concrete sedimentation tanks have a combined detention period of 2 hours at the design rate of flow. They are each 80 ft. long by 16 ft. wide by 10 ft. water depth, and are equipped with Jeffrey conveyor-type mechanism for continuous removal of sludge and scum. The clarified sewage leaving the tanks receives a secondary application of chlorine and passes through 1,050 feet of 30 in. and 24 in. cast iron pipe into deep water of the lake about 400 feet from shore.

The sludge and scum collected in the sedimentation tanks flow to a sludge manhole, whence they are pumped by Chicago screw feed pumps to the two reinforced concrete sludge digestion tanks.

The capacity of the sludge digestion tanks is 3 cu. ft. per capita of contributory population. The tanks are circular in plan, 45 ft. in diameter and 21 ft. side depth. They are equipped with Hardinge mechanism for stirring sludge at bottom of tank and scum at the top. Four coils of 2 in. wrought iron pipe are provided for heating the sludge. The roof slopes up to the center to a gas dome for collection of sludge gas. Excess liquor is decanted by gravity to the inlet of the sedimentation tanks. Digested sludge is discharged into a sludge chamber, from which it flows to the drying beds or can be re-circulated by the sludge pumps.

The two sludge drying beds are each approximately 40 ft. by 150 ft. in plan and have a total area equivalent to 0.5 sq. ft. per capita. They are glass enclosed and consist of 6 in. of sand and 8 in. of graded stone underdrained by 4 in. tile pipe, 6 ft. on centers. The effluent from the underdrains flows to the suction chamber at the head house. An overhead mono-rail system provides for removal of dried sludge.

The boiler for heating sludge, together with appurtenant equipment and the sludge pumps, is located in a small heater house. Be-

tween this building and the sludge digestion tanks is an underground pipe gallery in which are located and readily accessible all sludge, gas, hot water and sludge sampling pipes.

Laboratory facilities for control of operations are provided in the head house.

## Operation of Plant

The Gulvin Park Plant was put in operation October 12, 1935. Prior to this date the trunk sewers, which were below water level, had been flooded continuously and as a result large accumulations of sewage solids, grit and grease had collected in the sewers and in manholes. When pumping started, the water level was reduced and velocities in the sewers increased. As a result, a large mass of partly digested sludge, grease and other matter was immediately brought into the plant, filling the grit sump and stalling the cleaning rake of the mechanical screen. Great slabs of grease piled up on the manual screen when it came into operation. After cleaning the grit sump, the automatic screen was kept in operation continuously and was able to handle the large volume of matter which was swept in. Screening operations were further complicated by the operation of a canning factory which, through their faulty screening arrangement, dumped beet refuse into the sanitary sewer. For a time, it required the services of a man 24 hours a day to remove and replace the cans which received the screenings. This difficulty was overcome, with the cooperation of the State Department of Health and the canning factory, by the installation of a new drum-type screen by the canning factory.

Aside from these special conditions during the early operation of the plant, the screening operations have not been abnormal. Volume of screenings has gradually reduced from 32.5 to 11 cu. ft. per m.g. with an average of 12.2 cu. ft. Screenings are hauled twice daily to the city dump and burned.

Chlorine is added to the screened sewage before it enters the sedimentation tanks, in order to reduce odors. Chlorine residual tests are made frequently during the day in order to maintain a residual of 0.5 p.p.m. During dry weather, when the canning factory is not discharging wastes, the chlorine demand averages 16 p.p.m., but when beet wastes are being received, the demand has reached 43 p.p.m. at times. With a very large dose of chlorine, it is possible to bleach out the organic coloring matter from the beet wastes.

Frequent bacteriological tests on the effluent are made by Mr. Egglington, City Bacteriologist.

A summary of the operating results from Jan. 1, 1936, through Aug. 31, 1936, is given in Table I.

The sedimentation tanks removed substantially all of the settleable solids and 77 per cent of the suspended solids from the screened sewage. B.O.D. was reduced 43 per cent, but the reduction was affected adversely by the organic load from beet wastes. Sludge was withdrawn twice daily to the sludge collection manhole. Drawing of sludge was

TABLE I.—*Gulvin Park Treatment Plant, Geneva, New York*
*Operating Data, January 1 to August 31, 1936*

| Item (1) | Average Daily (2) | Maximum Daily (3) | Minimum Daily (4) | Average Monthly (5) |
|---|---|---|---|---|
| Sewage flow in 1,000 gallons | 1,545 | 10,125 | 300 | 46,949 |
| Screenings Cu. Ft. per million gallons | 12.2 | 32.5 | 11.0 | — |
| Raw sludge pumped | | | | |
| Cubic feet | 1,369 | 2,300 | 890 | 41,469 |
| Lbs. dry solids | 1,380 | — | — | 41,500 |
| Per cent solids | — | 2.8 | 1.0 | 1.6 |
| Per cent volatile matter | — | 76 | 62 | 70 |
| pH | — | 6.6 | 6.0 | 6.4 |
| Digested sludge Removal | | | | |
| Cubic feet | — | — | — | 1,482 |
| Lbs. dry solids | — | — | — | 13,250 |
| Per cent solids | — | 17.3 | 13.2 | 14.3 |
| Per cent volatile matter | — | 36 | 30 | 34 |
| pH | — | 7.3 | 6.8 | 7.0 |
| Gas Production | | | | |
| Cubic feet | 12,003 | 18,926 | 4,201 | 364,585 |
| Per cent $H_2S + CO_2$ | — | 31.4 | 27.4 | 29.1 |
| Cubic feet per capita | 0.7 | 1.11 | .25 | — |
| Chlorine used—ppm. | — | 27.1 | 8.1 | — |

| Item (1) | Influent (2) | Average Daily Results | |
|---|---|---|---|
| | | Effluent (3) | Per cent Removal (4) |
| Settleable solids—C.C. per Liter | 7.3 | 0 | — |
| Suspended solids—ppm. | 332 | 75 | 77 |
| B.O.D. (Average monthly) ppm. | 468 | 266 | 43 |
| pH | — | 7.1 | — |

continued until the moisture content was about 99 per cent. The average solids content of the sludge was 1.6 per cent. Sludge pumps were operated at the rate of 90 gallons per minute, pumping alternately to each digestion tank daily, a routine which has worked out very satisfactorily. Scum was removed from the sedimentation tanks twice daily and pumped to the digesters.

One of the digestion tanks was seeded at the start of operations with 60,000 gallons, 23 per cent of its capacity, of digested sludge transported by tank truck from the Newark N. Y., sewage plant. Fresh solids and sewage were pumped to the tank until it was filled and sufficient lime added to maintain a pH of 7.2. The water seal of the gas dome was closed and the stirring mechanism started, resulting in the production of gas within a few hours.

The second digester was seeded by means of supernatant liquor from the first tank, with the addition of small quantities of raw sludge and milk of lime from time to time.

A temperature of 86° F. is maintained in the digesters with very satisfactory results. Hot water is circulated at the rate of 1 cu. ft. per minute. The boiler has automatic temperature control and recording thermometers are located in feed and return lines.

Gas production is measured by meters and is fairly uniform. It has varied from 0.25 to 1.11 and averages 0.7 cu. ft. per capita.

No scum troubles have been experienced. Water sprays in the gas domes are operated ten minutes per day while pumping fresh sludge.

Digested sludge is withdrawn to the digested sludge chamber when fresh sludge is pumped. From this chamber it flows by gravity to the drying beds. The sludge averages about 14 per cent solids with a volatile matter content of 33 per cent on the dry basis.

Drying time on the beds varies from 15 to 20 days. The dried sludge is given to various clubs and nursery companies for use on lawns and shrubs. It is hoped that the results obtained thereby will create a demand for the sludge which will aid us to exact some revenue from its sale.

The plant was constructed with Federal assistance under P.W.A. The actual total cost was as follows:

| | |
|---|---|
| Treatment Plant complete | $153,204.32 |
| Outfall Sewer | 30,000.00 |
| | $183,204.32 |

Operating expenses, exclusive of fixed charges, for the period January 1 to August 31, 1936, were as follows:

| | |
|---|---|
| Salaries | $3,645.00 |
| Electric power and gas | 1,235.52 |
| Chlorine | 494.79 |
| Lime | 111.63 |
| Maintenance | 247.10 |
| Cleaning beds | 69.79 |
| Extra labor | 75.89 |
| Truck-gas oil | 40.70 |
| Miscellaneous | 208.56 |
| TOTAL | $6,128.98 |
| Million gallons treated | 375.597 |
| Cost per million gallons | $ 16.32 |

Design of the plant and general supervision of construction was under the direction of the late Nicholas S. Hill, Jr., Consulting Engineer of New York City. Mr. James W. Brennan, City Engineer, and Mr. Tom Bolin, Assistant City Engineer, were in direct charge of construction. The writer is in charge of operation and wishes to acknowledge the helpful cooperation of Mr. Brennan, the Board of Public Works and the Consulting Engineer.

# PROBLEMS IN SEWAGE TREATMENT AT STATE INSTITUTIONS *

By Charles W. McBreen

*Chief Engineer, Rockland State Hospital, Orangeburg, N. Y.*

Rockland State Hospital, near Orangeburg, N. Y., is one of the most modern of the large group of hospitals for psychopathic cases developed by this state in recent years. It was originally planned to care for about 5000 patients and employees.

It is located in the open country about 2 miles directly west of the Hudson River and 17 miles north of the George Washington bridge plaza; it comprises a group of about 70 buildings, covering an area of nearly 250 acres.

Sewage Treatment Plant, Rockland State Hospital, Orangeburg, N. Y.

The sewage plant was designed for a population of 6000 at 200 gallons flow per capita; it was put into operation about Nov. 1, 1930, at which time the population consisted of only a few employees. The first patients were received in Jan., 1931; continuing from that date, the population increased until the latter part of 1931 it reached approximately 5000 and has continued about this number up to the present time.

* Presented at the Fall Meeting of the New York State Sewage Works Association, Geneva, New York, October 9–10, 1936.

The plant consists of four Imhoff tanks, bar screen, three dosing tanks, trickling filters, secondary settling tanks, two glass-covered sludge beds, a pumping plant and a chlorination station. All sewage flows to the bar screen by gravity.

The primary tanks are of the Imhoff type, with a grit trough at either end, and with piping so arranged that the flow can be reversed. Dosing tanks are single units, three in number, piped so one, two or all can be operated as required; each of the three tanks has a dosing siphon, and a capacity of approximately 3000 gallons at normal flow. We operate on one dosing tank, to equalize the spraying period of the trickling filter with the rest or filling period of the dosing tank. Tanks are alternated in use.

The trickling filter has a pipe gallery in the center of the bed, with valved laterals running to either side. Type C full and half-spray nozzles are used, spaced 3 ft. from the outside of the bed. Each succeeding lateral is run on 10 ft. centers in alternate rows of 7 and 8 nozzles to each lateral. The filter media is 5 ft. deep, and is composed of two to three-inch crushed stone. The total area of the two beds is 35,984 sq. ft. Nozzles on the end of laterals are removed semi-weekly during one dumping of the dosing tank, which flushes out any grease accumulations, thus obviating frequent cleaning of nozzles.

We have never had any pooling; the fungus growth is average, and there is an abundance of ground worms. About July 1, 1936, we developed one of the finest growths of snails you ever saw. A few weeks ago, the secondary tanks were cleaned, the sludge pumped to the glass-covered bed and when dried, I would estimate 4 or 5 bushels of these small snails in a pile where the sludge discharged into the bed. The top of the stone bed is covered with millions of these small scavengers. They first appeared at one end of the north bed, and their action was very interesting as they gradually increased until the entire bed was cleaned.

The secondary sedimentation tanks are 45 by 15 by 11 ft. 6 in. deep, with three hopper bottoms in each tank. Each hopper has one suction pipe valved and connected to a sludge pump so any hopper can be pumped independent of the others. There are two units so one can be dewatered and thoroughly cleaned frequently; normally both tanks are in service.

Each day sludge is drawn from one compartment. There being six compartments in the two tanks, the complete cycle requires one week. This sludge, being quite liquid, was formerly pumped direct to the screen chamber. Some difficulties have been experienced at times with this process.

Two solution-feed chlorinators are used; one unit for pre-chlorination, discharging at the point of entrance of the main sewer, the other for post-chlorination, discharging the solution into the line between the trickling filter and secondary tanks.

There are three vertical pumps, with a total capacity of 1500 gallons per minute.

The outfall sewer extends approximately 4 miles from the pumping station to a small creek about 1 mile from the Hudson River. This sewer causes much annoyance to the population living in the vicinity of the discharge. While we are able to show a trace of chlorine at the outlet, we feel there is no cause for alarm. Nevertheless, there are certain periods when a fine algae growth appearing like paper pulp is very prominent at the outlet.

SEWAGE PROBLEMS SOLVED AND UNSOLVED AT ROCKLAND

| *Method* | *Result* | |
|---|---|---|
| Pumping of pre-digested sludge from hoppers of secondary tanks direct to raw sewage at screen, entrance of Imhoff tanks. | Found difficulty in keeping floc settled. Primary tanks hard to keep clean. At this time, slight foaming appeared in primaries. | This system tried for six months and discontinued. Result: Cleaner Imhoff tanks and absence of unsettleable floc. Foaming stopped, also pH value increased. Secondary hoppers now pumped to drying bed. |
| Middle of July, 1936, a growth of small snails developed in the beds, origin unknown. This apparently accounted for the continued unloading of the beds during the summer. | Result: 75 per cent removal of accumulated algae growth from stone in the beds. Condition still prevalent. Beds in better condition. | Question: Is it advisable to allow the stone to clear up entirely, eliminating natural element necessary to bacteria growth? |

Screenings per day, 4 cu. ft.
Settleable solids, c.c. per liter: Influent — 11.7. Effluent — 0.38. Filtered effluent .24.
40–45 lb. chlorine per day.
Chlorine residual, 0.4 to 0.5 p.p.m.

The chlorine residual is taken at the suction of the pump after the effluent has passed through the secondary tanks, to get a more representative reading.

Much undigestible material is removed from the bar screen. From 150 to 200 pieces of usable laundry are returned to the laundry each week. This material is washed and sterilized, then returned to the buildings where it came from. Scrub rags and grease are most common.

The hospital has been extended to a greater capacity than originally intended, consequently it has become necessary to increase the capacity of the sewage works. Construction is now progressing on an additional primary tank, trickling filter, glass-covered sludge bed, secondary sedimentation tank, and storage reservoir. A mechanically cleaned screen with screenings grinder is also being installed. These additions will increase the capacity fifty per cent.

## Discussion

By Henry Ryon

*Senior Sanitary Engineer, State Department of Public Works, Albany, New York*

In general the problems in sewage treatment at state institutions are similar to those encountered in the treatment of municipal sewage. Institutional sewage has, however, certain characteristics not commonly found in most municipal sewages.

The first and most noticeable of these is the quantity of sewage that must be treated. Eighteen of the institutions of this state, with a total population of about 64,000, have fairly accurate means of measuring their sewage flow, and the average rate of sewage flow at these institutions, for the first half of this year, was 170 gallons per capita per day. The lowest rate was recorded at one of the prisons, where the average per capita flow was 100 gallons per day, and the highest at one of the hospitals for the insane, where the average per capita flow was 295 gallons per day. The peak rates of flow for short periods are generally about three times the average while the minimum rates drop in some cases to about 10 per cent of the average.

These large flows are apparently not due entirely to dilution, for the settleable solids in the raw sewages average about 7 cc. per liter, while the total solids vary from 400 to 700 p.p.m., and the 5-day B.O.D. from 200 to 400 p.p.m.

This matter of rates of flow is, of course, a problem for the designing engineer rather than the plant operator. All pumps, weirs, siphons and similar equipment must be designed for the peak flows, and all units must have a greater per capita capacity than those usually provided for municipal plants, with the result that the cost of an institutional plant is much greater than that of a municipal plant for the same population.

A second characteristic of institutional sewage which is very noticeable is the temperature. The raw sewage temperatures at different institutions of this state vary from 60° F. to 90° F., with an average of a little over 75° F. These high temperatures are beneficial rather than detrimental at the sewage plants proper, particularly during the winter months, but they do interfere considerably with the operation of the grease traps. The usual arrangement at the institutions has been to install a concrete grease trap having a capacity of from 1½ to 2 gallons per capita on the sewer from each kitchen. In many cases, however, the wastes are so warm that the grease will not congeal in these traps and passes on to the disposal plant. Recently the chief engineer of one of our institutions after a little experimenting found that he could partially correct this difficulty by turning cold water into traps. The kitchens were equipped with water cooled refrigerating apparatus, and the waste water from these machines served to cool the traps in a fairly satisfactory manner. The grease at this institution is particularly troublesome because a considerable amount of it congeals on the walls of the pump well and finally breaks off in lumps sufficiently large to

clog the 4-inch centrifugal pumps which lift the sewage of the institution.

The grease just mentioned, is present in greater quantity in institutional sewage than in the average municipal sewage. This requires more skimming of clarifiers and more attention to the gas vents of Imhoff tanks because of the formation of scum instead of sludge. It has been found necessary in most Imhoff tank installations to provide pipes for drawing off the scum at intervals either into small separate digestion tanks or directly onto the sludge beds. At one institution where all the solids in the settling tanks rose to the top instead of settling to the bottom and could not be sunk nor readily dipped out by hand on account of the large volume, the chief engineer devised a rather novel means for removing these solids. He rigged up a crane with a boom long enough to reach all the gas vents and he built a bucket just large enough to enter the vents. This device has proved very effective for removing the heavy scum.

Another peculiarity of institutional sewage, especially that from hospitals for the insane, is the large quantities of rags it contains. Bar screens, if frequently raked, will remove most of these rags, but the long narrow strips which patients seem to enjoy tearing from their sheets and feeding down the toilets will, if not immediately removed, work through the screens and clog valves, pumps and other apparatus. One institution has found it necessary to keep its mechanical screen cleaner operating continuously to prevent rags from passing through the screen. Another institution has installed manholes with spikes projecting from their bottom to catch the rags as they leave the buildings and prevent their clogging the sewer lines. With some types of mechanical screen cleaners trouble has been experienced due to rags becoming wrapped around parts of the equipment. The average hospital recovers from 150 to 200 pieces a month, towels, scrub rags and underwear, at the screens and returns them to the laundry. The salvagable rags, of course, are only a small percentage of the total. In connection with the recovery of material from the sewage it may be interesting to note that when it was proposed to use a comminuter instead of a bar screen at one institution the superintendent promptly objected because the salvaged material would be lost.

In his paper on the sewage disposal works of the Rockland State Hospital, Mr. McBreen has mentioned the spread of snails over the stones of the trickling filters and the removal by them of the gelatinous coating of the stones. Some fear has been expressed that this removal of the coating may reduce the efficiency of the beds. At the Rome State School, a similar growth of snails started in one corner of one of the beds about two years ago and has spread until practically the entire area is now covered. The growth has eliminated the trouble previously caused by pooling, and during this period the effluent, as indicated by the methylene blue test, has materially improved. This of course, does not prove that the increase in efficiency was due to the snails, but but does seem to indicate that the snails, so far as we now know, have as yet done no harm.

A rather interesting problem developed recently at the Hudson River State Hospital Sewage Disposal Works that may be of interest to operators having separate digestion tanks and gas generation. The plant has been in operation a little over three years and for the past year or so the gas production has been falling off until a few weeks ago it stopped entirely. After some investigation the chief engineer of the institution found that the wrought iron pipe line from the digestor to the heater house was so badly corroded that all the gas leaked out before reaching the drip pot in the house. The corrosion was worst along the invert of the pipe. The cement joints in the tile pipe which enclosed the wrought iron pipe were also eaten away. The pipe was buried deep in an embankment and its replacement would have been rather expensive, but the trouble was promptly corrected by running a covered pipe overhead. While this is now serving satisfactorily and can be easily replaced if necessary, it would be interesting to know what kind of pipe will best resist the corrosive action of gas.

# IMPROVEMENTS IN TRICKLING FILTERS *

By Karl Imhoff

*Consulting Engineer, Essen, Germany*

Translated by F. W. Mohlman

Various improvements in trickling filters have been proposed in recent years. All contributors to this development have agreed that the trickling filter can be dosed with sewage much more heavily than has heretofore been customary. However, the technical means for obtaining these higher rates vary widely, and still more variable are the scientific hypotheses employed to explain the basis of the improved performance.

Stroganoff ("Aerofilter") believed that the improvement was due to the use of artificial aeration and fine filter media. Bach and Blunk ("Vacuum Trickling Filter") emphasized the value of complete enclosure and aeration by suction,[5] and Jenks [6] ("Biofiltration") investigated the multiple recirculation of the filter effluent in combination with a detention tank.[7] Halvorson [8] ("Aerofiltration") claimed the essential factor was continuous dosage at high rate, which prevented storage of solids in the filter.[9]

Fine material was used by Stroganoff (.2 to .6 in.). It has not been proven, however, that one can avoid stoppage, in the long run, with such fine material. Halvorson and Jenks have obtained good results at high rates of dosage with coarse filter media (1.5 to 3.0 in.). Therefore fine material is not essential and it is not to be recommended.

Artificial aeration was investigated and described in 1891 by Waring.[4] He employed compressed air, which was blown in at the base of the filter. Hering,[4] in 1909, used ventilators at Atlanta for the same purpose. Halvorson has reported that natural aeration of the filter occurs through differences in the temperature of the sewage and the atmosphere. In summer the air current passes downward, in winter upward. A temperature differential of 4° C. (7° F.) was sufficient for an air rate of 1 cu. ft. per sq. ft. per minute. Jenks, however, used a filter 3 ft. deep without artificial aeration.

Enclosure of the filter has often been advocated. An example is the installation by Dittler in Naumberg in 1905. There the air was sucked through a stack 60 ft. high. In Dittler's Austrian patent (No. 36990, year 1907), the stack is called an "aspirator."

The return of effluent was first used in England. Dr. Fowler [2] adopted recirculation in 1911 and 1912 at Manchester for the purification of phenol-containing sewage. In the Emscher District at Essen, recirculation was used with the Stoppenberg [3] trickling filter in 1913 for the same purpose. In England recirculation is still used, for example at Bradford and Bury.[10] At Manchester and Stoppenberg a

* Received Jan. 15, 1937; abstract of an article to be published in *Gesundheits-Ingenieur* in February, 1937.

10-fold recirculation of effluent was practiced. Jenks recommended, in one case, 6-fold recirculation with a dosage of 12 m.g.a.d. of the undiluted influent. Halvorson, in an experimental plant, recirculated dairy wastes 4-fold in order to dilute the B.O.D. to 200 p.p.m.

Halvorson has demonstrated convincingly that continuous percolation at a high rate is extremely important. He recommends, in place of the usual dosage in American plants of 2 m.g.a.d., a rate of 20 m.g.a.d., a 10-fold increase. He has obtained results at this rate almost as good as those obtained at the usual low rates. His observations throw a new light on many problems and the flushing action of the high rates of flow may furnish the explanation for the results obtained by other investigators, although explained otherwise by them. Levine [11] attained a dosage of 16 m.g.a.d.

Odors and flies are avoided by enclosure of the filter. The high-rate filter is also free from flies, according to the observations of Halvorson and Jenks, and the recirculation of the purified effluent prevents odors which may perchance be present in the influent.

It must be determined, through further investigations in large sewage works, within what limits concentrated sewages must be diluted by recirculation of effluent and by what type of construction artificial aeration may be obviated in spite of high-rate dosing.

### References


1. K. Imhoff. "Biological Sewage Treatment in Germany," Seventh Volume, *Mitteilungen der Landesanstalt*, p. 30 (1906).
2. G. J. Fowler and A. L. Holton. "Experiments on the Bacterial Purification of Ammonia Recovery Liquor," *J. Soc. Chem. Ind.*, **4**, 180 (1911).
3. "Twenty-five Years of the Emscher District," chapter by H. Bach, "By-products Coke Wastes in the Emscher District," p. 270 (1925). First published in the 1920 Report of the E. D., pp. 45–46.
4. K. Imhoff. "Progress in Sewage Treatment," *Second edition*, p. 58 (1936).
5. H. Bach, "Oxygen and Carbon Dioxide in Trickling Filters," *Gesundh.-Ing.*, p. 189 (1933).
6. H. Blunk. "Process for De-gasification and Aeration of Sewage Undergoing Biological Purification," Swiss Patent, 172,741. Sept. 11, 1933.
7. H. N. Jenks. "Biofiltration of Sewage," *Eng. News-Record*, p. 721 (1936).
8. H. N. Jenks. "Experimental Studies of Biofiltration," *This Journal*, p. 401 (1936).
9. H. O. Halvorson. "Aerofiltration of Sewage and Industrial Wastes," *Water Wks. and Sewer.*, p. 307 (1936).
10. K. Imhoff. "Sewage Treatment Trends in England," *Eng. News-Record*, p. 8 (1936).
11. Max Levine, *et al.* "Observations on Ceramic Filter Media and High Rates of Filtration," *This Journal*, p. 701 (1936).


### Addenda by Translator


12. H. O. Halvorson, *et al.* "Some Fundamental Factors Concerned in the Operation of Trickling Filters," *This Journal*, p. 888 (1936).
13. F. W. Mohlman. "One Year's Operation of an Experimental High-Rate Trickling Filter," *This Journal*, p. 904 (1936).

# Operators' Reports and Suggestions

W. D. Hatfield

219 Linden Place, Decatur, Illinois

## GADGET CONTESTS

An ever increasing interest is being shown by the individual federated associations in gadget contests at their regular meetings. The prize winning gadgets at the Ohio Sewage Works Conference were described in the September issue of *This Journal;* in this issue are the winners of the New York Sewage Works Conference contest and the Central States Association. Some of the associations are offering cash prizes and others are presenting certificates of honorable mention.

Mr. A. S. Bedell, Secy.-Treas. of the New York State Association writes, "Both the committee and myself are very well pleased with this new venture of ours, and from the conversations overheard it would appear that we can count on quite a number of exhibits at future meetings. It is the same story—many men had little gadgets but were ashamed to present them, feeling that they were too simple."

### Pictures and Drawings

In some cases pictures of gadgets are satisfactory, but in most cases line drawings with dimensions, on plain white drawing paper or blue drawing cloth, are more satisfactory. Wherever possible these drawings should be made on manuscript size paper 8.5 by 11 inches. The drawing should be made with the idea that they will be reduced to a size for the page in the journal. A short description of how the gadget works and how it is made should accompany the illustration.

W. D. Hatfield

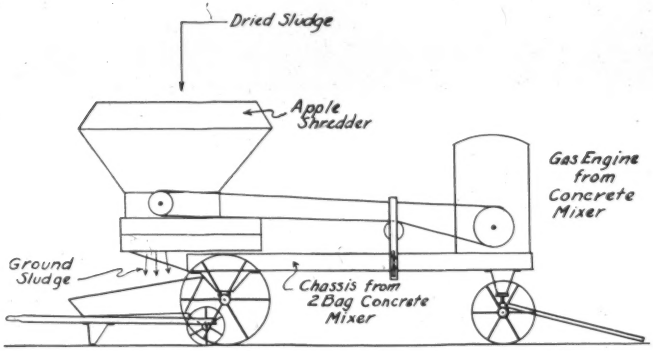
## NEW YORK STATE SEWAGE WORKS ASSOCIATION—GADGET CONTEST, GENEVA, N. Y., OCTOBER, 10, 1936

First Award: Sludge Grinder

By John R. Woodford

*Retired Superintendent of Sewers, Ithaca, N. Y.*

Sludge grinder and shredder for processing dried sludge for use as fertilizer. Constructed from a concrete mixer chassis (formerly driven by a gas engine) and the grinder section of an old cider mill. (Fig. 1).



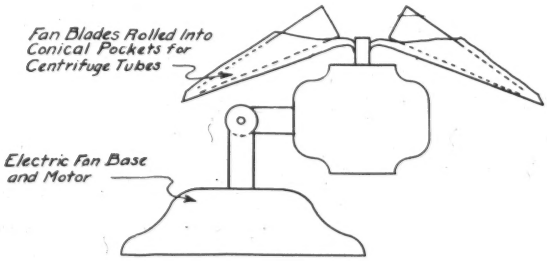

SLUDGE GRINDER

SECOND AWARD: LABORATORY CENTRIFUGE

BY C. G. ANDERSON

*Superintendent of Sewerage, Rockville Centre, N. Y.*

A device for centrifuging sludge samples in the laboratory. Constructed from a four-blade electric fan with two of the opposing blades cut and bent into centrifuge tube holders, the remaining two blades being removed (Fig. 2).



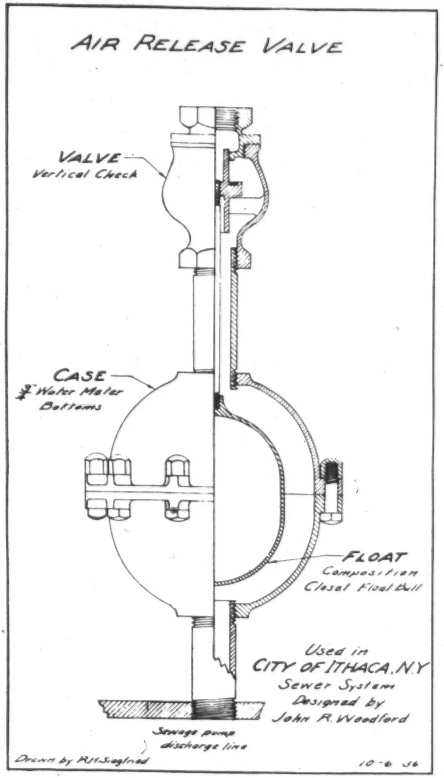

LABORATORY SLUDGE CENTRIFUGE

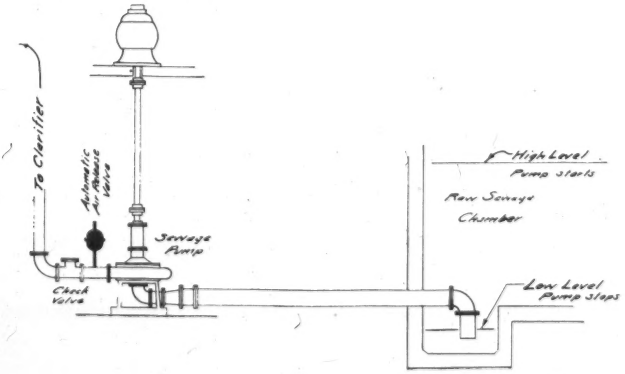
THIRD AWARD: AIR RELEASE VALVE

BY JOHN R. WOODFORD

*Retired Superintendent of Sewers, Ithaca, N. Y.*

A device to bleed and overcome the air binding of a centrifugal pump. Constructed from a vertical check valve nippled to a case made of three-quarter inch water meter bottoms; the case containing a composition closet float valve which actuates the vertical check valve (Figs. 3 and 4).


AIR RELEASE VALVE
VALVE
Vertical Check
CASE
8" Water Meter
Bottoms
FLOAT
Composition
Closed Float Ball
Used in
CITY OF ITHACA, N.Y.
Sewer System
Designed by
John R. Woodford
Sewage pump
discharge line
Drawn by R.H. Siegfried
10-6-36


To Clarifier
Automatic
Air Release
Valve
Sewage
Pump
Check
Valve
High Level
Pump starts
Raw Sewage
Chamber
Low Level
Pump Stops

# CENTRAL STATES SEWAGE WORKS ASSOCIATION—GADGET CONTEST, INDIANAPOLIS, IND., OCTOBER 29, 1936

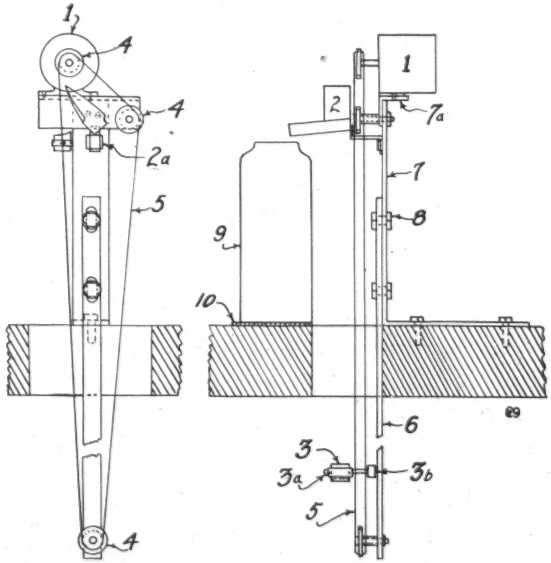
## First Prize: Automatic Sampler

By George Martin

*Superintendent, Metropolitan Sewerage District, Green Bay, Wis.*

This sampler, which consists of a bucket or buckets mounted on a ladder chain, driven by a gear reducing motor, is so constructed that the buckets fill at the bottom of their run and discharge into a trough at the top of the run. (See Fig. 1.) As the speed of this unit is constant, the volume of sample collected can be changed by changing the number or size of the buckets. However, the speed of the motor can be changed by a rheostat in the motor circuit. To take up slack in the chain the drop leg can be lengthened. The parts and cost of this sampler are as follows:

| | |
|---|---|
| Flexo-Action Motorized Reduction Unit, Merkle-Korff Gear Co., 213 N. Morgan St., Chicago, Illinois | $5.15 |
| Bronze Sprockets No. CB3-10, Western Iron Stores, Milwaukee, Wis., 3 @ 85¢ | 2.55 |
| Brass Ladder Chain No. 2, Western Iron Stores, Milwaukee, Wis., 8 ft. @ 15¢ | 1.20 |
| Miscellaneous | 1.00 |
| Total Cost | $9.90 |




Sampler

*Sampler Material Schedule*

1. Merkle-Korff Gear Co., 213 N. Morgan St., Chicago, Ill.—flexo-action motorized reduction unit, integral shaded pole induction motor, clockwise rotation, output shaft speed 12 R.P.M., fan cooled.

2. Trough 3½ in. long made of galvanized sheet iron (removable).
2a. Trough supporting bracket.
3. Buckets size as desired, made of galvanized iron (removable).
3a. Bucket bracket soldered on outside of chain so that bucket is vertical when chain is traveling up.
3b. Bucket counter weight (lead).
4. Bronze sprocket, No. CB3-10, Western Iron Stores Co., Milwaukee, Wisconsin.
5. Brass ladder chain, No. 2, Western Iron Stores Co.
6. Drop leg 1 in. by ¼ in. iron.
7. Motor stand 2 in. by ¼ in. iron.
7a. Motor stand cross head 1¾ in. by 1¾ in. by ⅛ in., 5¾ in. long.
8. Bolts (½ in).
9. Mason jar (2 qt.).
10. Rubber mat.

## Second Prize: Portable Turbidimeter

By D. E. Bloodgood

*Engineer in Charge, Sewage Treatment Works, Indianapolis, Ind.*

The portable turbidimeter is used by the plant operator for determining the clarity of plant effluent by a method that is rapid and uniform, and it furnishes readings that are easily recorded for further use by the plant superintendent.

The turbidimeter consists of a 1¼ in. (inside) 0.065 in. wall aluminum tube 68 in. long with a sleeved brass collar on the bottom, into which the brass moisture proof lamp case screws. There are four ports in the cap which admit water but exclude all outside light. In the 1/32 in. metal disk there is cut a ¾ in. cross of 0.012 in. opening, with the center closed off by a piece of metal not larger than 3/32 in. in diameter, to blank out the bright spot caused by the bulb filament. The operation of the lamp is identical with the ordinary two cell flashlight, except for the self-operating mercury switch, which consists of a non-conducting box, two platinum contact points and a drop of mercury. The mercury making the contact between the two points only when the turbidimeter is in a vertical position.

The portable turbidimeter was calibrated by getting the submergence in effluents of known turbidity. In use the instrument is submerged to a point at which the cross disappears and then the scale on the side of the tube is read by looking into the six-sided mirror of the float.

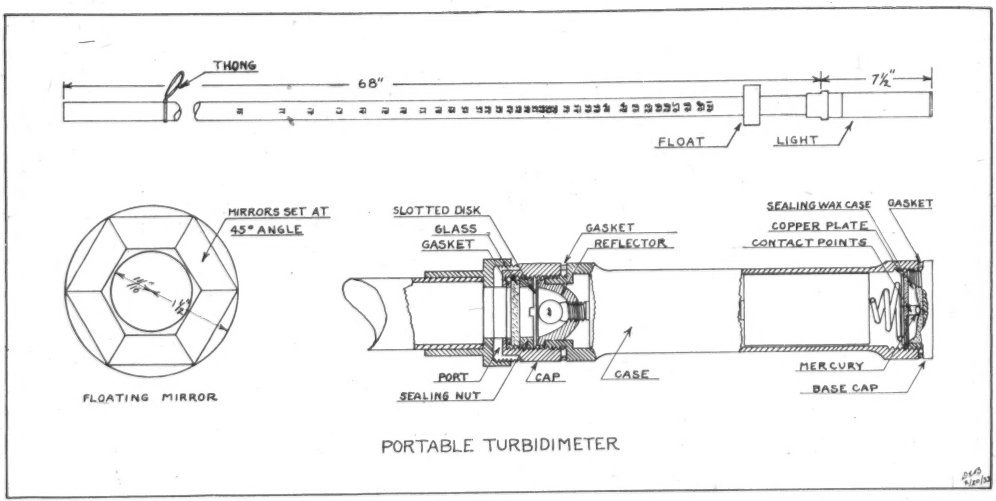
This gadet was designed and calibrated by Mr. D. O. Bender.

## Third Prize: Cheap Spacious 20° C. Incubator

By W. D. Hatfield and E. Schlie

*Sewage Treatment Works, Decatur, Ill.*

The accompanying diagram illustrates how a 20° C.–B.O.D. incubator can be made which meets the temperature specifications of 20° ± 0.5° C. throughout the entire chamber, and also has sufficient capacity to hold a 5-gallon carboy of dilution water and from 50 to 75 bottles for routine B.O.D. determinations or 20-day curves, etc. This capacity is not possible in the electrically operated 20° C. incubators now advertized on the market for prices from $250.00 to $495.00. (For the latter price an electrically operated refrigerator large enough to hold the dilution water bottle could be obtained.)




PORTABLE TURBIDIMETER

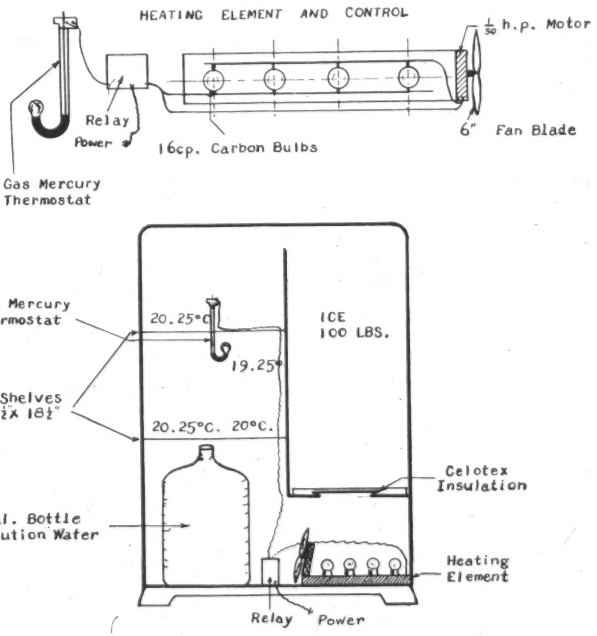
The price of the illustrated incubator, which has served us for years, is as follows:

| | | |
|---|---|---|
| 100 lb. ice refrigerator | | $50.00 |
| Gas-mercury thermostat and relay | | 18.50 |
| Heating element. | | |
| 1 1/50 hp. motor | $1.75 | |
| 1 6 in. fan (auto sup.) | .15 | |
| 4 sockets | .40 | |
| 4 16c carbon bulbs | .80 | 3.10 |
| TOTAL | | $71.60 |

The heating element is so wired that the speed of the fan is controlled by the number of carbon bulbs used in the circuit. The best method of operation is to use as few heating bulbs as possible. We are using only two of the four bulbs shown in the illustration.

An important factor in the consumption of ice is the Celotex insulation over the hole below the ice compartment. This has reduced the ice consumption from 50 or 100 lbs. a day to less than 150 lbs. a week.

Under these conditions of operation the box is maintained between 19.75° and 20.25° C. Better results would be obtained if the fan were wired on a separate circuit so that it operated continuously. In such a case the fan speed should be reduced by a rheostat so that the air circulation is gentle rather than violent.




CHEAP SPACIOUS 20° C. INCUBATOR. MAXIMUM VARIATION 19.25–20.25° C.

# MORE EXCERPTS FROM THE DIGESTER

Edited by W. H. WISELY, *Assistant Sanitary Engineer*
*Illinois State Department of Public Health, Springfield*

## RAY CORR GETS TO THE CORE SO THAT TROUBLE WON'T RECUR

Ray Corr (Woodstock), comes through with something of interest to activated sludge plant operators. This is an excellent example of the manner in which operating reports and laboratory results can be used in a practical way.

The raw sewage pH at Woodstock has been consistently about 7.4 and the normal activated sludge index well below 200. On about July 26, 1936, Ray noticed that the raw sewage pH began to drop and the sludge index began to increase, indicating the onset of bulking. A noticeable decrease in dissolved oxygen in the aeration tanks was also noted.

Corr began looking for trouble right away and on July 28 he found an obstruction in the sewer to the plant that was holding back the sewage and allowing it to become septic (the reason for the drop in pH). The obstruction was removed immediately, but the bulking continued to become worse until August 5, when the sludge index reached a maximum of 550.

By placing a spare aerator in service about this time, Ray began to overcome the trouble and within two weeks he brought the sludge index down to 115. At no time during the struggle did the plant effluent suffer greatly because *Corr had found and corrected the cause at the very beginning.*

## SOME WINTER OPERATION HINTS

*Chain Flight Settling Tanks:* The application of heavy tractor oil to the chains has been found to eliminate ice formation which frequently causes chain breakage.

*Floating Cover Digesters:* A little ice cream salt scattered on the surface of the narrow ring of scum between the wall of the tank and the cover is helpful in preventing ice formation at this point.

Where the overhead gas line is used with this type of cover, a water connection for back-flushing the line combats freezing of condensate, according to Burgeson (Geneva).

*Imhoff Tanks:* Frequent attention to gas vents will circumvent freezing. Don't let a thick layer of scum accumulate.

*Mechanical Aerators:* Hofland (Dwight) has found that covering this type of unit with a plank roof in winter eliminates ice trouble and does not interfere with purification.

Corr (Woodstock) suggests painting vane type aerators with heavy tractor oil to serve the same purpose.

*Trickling Filters:* In our original list we neglected to mention covering dosing tanks with a plank roof to prevent freezing of the siphon piping. This is done to good advantage at a number of plants.

Corrington (Clinton) offers that closing two or three nozzles at the outer end of revolving distributor arms will eliminate the ice ring around the edge of filters of that type.

*Sand Filters:* Schacht (West Chicago) advises the use of just enough filter beds to give a rest period that will give no more than a slight freeze between doses.

And now, little operators, before you climb into your little sludge beds and tuck the sludge blankets under your chins, here are a few things to remember about plant odors: odors:

1. Offensive odors come only from *stale* sewage and they form in the sewer coming to the plant or in the primary treatment units.

2. Do everything possible to keep the sewage fresh during treatment. Some suggestions:

(a) Keep sewers flushed clean.
(b) Keep bar screens clean and clear so that sewage is not backed up into the outfall sewer to the plant. A mechanically cleaned screen is valuable where a large amount of screenings is received.

(*c*) Dilution of the sewage with stream water or plant effluent is helpful. For instance, you can operate your final settling tank sludge pump continuously during critical dry weather periods, thus diluting the raw sewage with plant effluent.

(*d*) In dry weather, reduce the detention period in the primary settling tanks to the minimum time which will permit good removal of settleable solids. In many plants having two or more primary settling units, it is only necessary to use one unit in dry weather.

(*e*) The proper application of chlorine to the sewage will control the formation of hydrogen sulfide. For best economy, chlorine should be applied to the sewage before 3.0 p.p.m. of hydrogen sulfide is present. Don't make a chlorination installation without qualified advice.

(*f*) Hydrated lime solution applied at some point on the outfall sewer to the plant will also keep the sewage fresh until it reaches the treatment units. Such treatment would be necessary only in extreme dry, hot weather.

3. Any gases which have formed in stale sewage will be given off to the atmosphere wherever the sewage splashes or is sprayed, for instance at a sprinkling filter. The careful location of trees and shrubs, which serve to disperse odors, is helpful. The prevailing summer winds and location of property likely to be bothered should be considered.

4. General cleanliness about the plant is essential. Don't let piles of screenings or grit lay around. Keep channels, tank walls and walks clean. Don't allow scum to accumulate.

## Extracts from Discussion on Foaming of Digestion Units

What would happen if we hauled 10 tons of garbage a day to a hog pen which enclosed only 1 pair of hogs? Wouldn't it be likely that this enormous amount of foul material accumulating day by day would create such conditions that even the hogs would soon become sick? If we load a sludge digestion tank with a large amount of raw sludge when the tank does not contain enough bacteria (hogs) to consume it, the same thing occurs—the bacteria become sick and show it by causing the tank to foam, and that is how foaming so often results in starting up a new digester.

Three ways to start a new tank into operation:

1. "Seed" the tank first with active sludge from another digester (if available). The "seed" sludge *must* be actively digesting—completely digested sludge is no good for this purpose. The use of dead leaves has been suggested for this purpose instead of sewage sludge. (We don't guarantee this, however.)

2. Start the tank slowly by adding small daily charges of sludge, gradually increasing to the full daily charge.

3. Use lime to delay full activity of sludge until a "seed" develops. The lime acts as a drug when used in this way and may be eventually discontinued.

Some causes of foaming:

1. Excessive loading of a digester with raw sludge in an amount greater than the "seed" sludge can handle. A sludge storage tank or lagoon is necessary if the raw sludge load is too great.

2. Seasonal variation of temperature in unheated tanks. In the winter, raw solids are added daily even though digestion activity is retarded because of low temperatures. In the spring, the activity of digestion increases with rising temperature and the digestion bacteria must "catch up." They become overworked and foaming frequently results.

3. Drawing too much sludge to the drying beds at one time may not leave enough seeding sludge for the digestion process to continue normally.

4. Certain industrial wastes may cause foaming, among which are starch, milk or brewery wastes.

What to do with a foaming tank:

1. Circulate supernatant liquor to gas collector or to gas vents (in the case of Imhoff tanks).

2. Gentle spray applied to surface of foam is beneficial in control. Supernatant liquor, sewage or water may be used. This is particularly useful in Imhoff tanks because the additional supernatant liquor (if sewage or water is used) can be easily handled.

3. Lime is helpful in controlling foaming but is not a cure. Adjustment of pH with lime assists in developing the proper conditions for good digestion. (Sample for pH of sludge should be taken from supernatant over actively digesting sludge.) A pH of 6.5–6.6 at this depth is not too low.

4. Chlorination of raw sewage has given beneficial results at some plants.

5. Resting a foaming tank (reducing the daily charge of raw sludge) will stop foaming, but this is only possible where more than one digestion unit is available.

## "SUNRISE BREAKFAST"—QUESTION BOX

FALL MEETING OF THE NEW YORK STATE SEWAGE WORKS ASSOCIATION, GENEVA, N. Y., OCTOBER 9 AND 10, 1936

IN CHARGE OF MORRIS M. COHN AND CHAS. C. AGAR

*Regarding the use of chlorinated iron for odor control as described at East Aurora, can you give more details as to the method employed—turning scrap iron or tin cans to ferrous chloride?*

(H. A. Faber, *The Chlorine Institute, Inc.*) This method of preventing hydrogen sulphide odors is coming into increasing use because of its economy and simplicity. The type of tower used must be resistant to corrosion. Tile pipes, two or three feet high, joined with acid-proof cement are often used, and a rich cement concrete tower is sometimes built. At East Aurora a rather unusual one is in use made of a heavy wood tank set upright and coated thickly with paraffin for protection of the inner surface. In any type, the chlorine water from a chlorinator is discharged at the bottom of the tower, flows upward in contact with scrap iron turnings or stampings or crushed tin cans. The ferrous chloride so produced is run from the top of the tower into the sewage which is septic or contains hydrogen sulphide. Control is simple, as ordinarily the dose may be either fixed or changed only twice daily. The dose required may be easily determined because each 2 parts of chlorine, passing through the tower to produce ferrous chloride, will react with one part of hydrogen sulphide. The method is economical because chlorine used alone reacts with organic matter as well as with the hydrogen sulphide, but the ferrous chloride reacts only with the hydrogen sulphide forming non-volatile iron sulphide and removing the odor-producing substance economically.

*Can the screenings from a ⅝-inch bar screen be used in a digestion tank?*

(L. Luther, *Supt., Freeport, N. Y.*) At Freeport screenings were first used in a digestion tank and caused no difficulty—perhaps because stirring was carried out. Now these screenings are shredded and returned to the inflowing sewage. They cause no trouble from floating.

(R. C. Sweeney, *N. Y. S. Health Dept.*) Observations at the North Adams, Mass., plant showed they had no difficulty in digesting such screenings and the operator of the plant mentioned none. At Cleveland, Ohio, solids did float, but there is a heavy industrial flow at the plant.

(Chas. Agar, *N. Y. S. Health Dept.*) It may be a coincidence but North Adams is having trouble with scum formation in the digestion tanks. Scum has been encountered 12–15 feet deep in the digestion tanks. The construction of the digesters is being changed in an attempt to remedy this—in the new plant—provision for stirring or recirculation is to be provided.

*Mention safety measures required at sewage plants.*

(W. W. Watkins, *Supt., Oneonta, N. Y.*) At the Oneonta plant the digesters are conspicuously posted to warn against fire hazard. There are two open flames beneath the gas boilers, but no other "loose" gas is allowed.

(Harry Eustace, *Supt., Ithaca, N. Y.*) Whenever the level in the digestion tank is drawn down particular precautions are observed. A safety lamp is used when the tank is entered, and the tank is first well aerated.

(L. H. Enslow, *Editor, Water Works and Sewerage.*) In his opinion round a properly engineered plant, signs are not essential. At Bristol, R. I., the explosion due to gas was due to inexcusable design. It is more economical to pay for danger-proof equipment in gas handling and proper precautions than for the results of an explosion.

(Chas. Agar, *N. Y. S. Health Dept.*). Believes signs are of real value to warn operators and visitors. There may be leaks through the gas meter, through the superstructure over the digestion tank, or where the flame is vented through the stack. The use of signs seems desirable in addition to precaution.

*If the pH changes from 6.0 to 7.0 does it go up or down?*

(E. B. Phelps, *Prof., Columbia Univ.*) He asked this question because of the confusion that exists in the use of the term. While the number goes up the pH goes down (i.e., becomes less acid). Operators are accustomed to use the first term, chemists the latter.

*What is the best lime to use—pebbled unslaked lime, commercial hydrated lime, or agricultural lime—for the adjustment of digester pH?*

(F. A. Cary, *Supt., Fairport, N. Y.*) At Fairport, hydrated lime mixed with hot water has been found best.

(Frank Holland, *Commissioner, Freeport, N. Y.*) The difference in limes is only a practical one. "Masons" lime is one containing 40 to 60 per cent magnesium. Other limes are 90 to 94 per cent calcium and only a trace of magnesium. Lime is hydrated to remove the heat of reaction, and leaves the same constituents. Steam is drawn off when slaking begins.

(Chas. Agar, *N. Y. S. Dept. Health.*) Agricultural lime, or ground limestone, $CaCO_3$, is not satisfactory for use in a digester, as this is only slightly soluble in water. Hydrated or "Plasterer's lime" is easiest to use. Whether it has a high calcium or magnesium content is not important as long as it will neutralize acidity. A high magnesium lime works satisfactorily. The pebbled or unslaked lime is merely a more concentrated form of calcium oxide. When water is added the hydrate is formed. He suggests a high-grade hydrate lime or pebbled lime be specified; the first is easiest to use, the second generates much heat during slaking.

(Wm. A. Ryan, *Chemist, Rochester, N. Y.*) The method of adding lime is more important than the amount—ordinarily too much is added. If several additions of small amounts of lime are added to sludge less will be required than if one large amount is applied at less frequent intervals.

(J. E. Ferris, *Electro Bleaching Gas Co., New York City.*) At the new Coney Island plant hydrated lime is used because it will not increase the temperature while pebbled lime would.

(H. M. Rath, *Operator, Coney Island Plant.*) Pebbled lime was first used at Coney Island but because of mechanical difficulties the hydrate is more successful. The lime is added to the suction line to recirculating sludge pumps.

(Chas. Agar, *N. Y. S. Health Dept.*) Observations over a period of years have shown the best method of application to Imhoff tanks (at least from a practical point of view) is to add dry lime to the gas vents. Though to add lime solution, or suspension, might be more efficient, the additional labor and time of application is impractical at most plants. By adding small daily increments and allowing them to dissolve slowly by not hosing down immediately this can be made efficient. If added to sludge, small daily amounts should be added as the sludge is pumped into the digester. It is important, if the digestion tank is acid, to determine by batch samples the quantity of lime needed. Sixteen years experience has shown that with domestic sewage five to ten pounds of lime per day per 1000 population will correct acid tank conditions for average sewage. However, over a month may be required to bring this correction about. The best way is to prevent it from becoming acid. By properly starting digestion, no further lime additions need generally be made. Experiences at State Institutions have shown their sewage to be different from the usual domestic sewage.

(R. D. Scott, *Central Islip, State Institution, N. Y.*) At his plant previously over 100 pounds a day were required but this has gradually been cut to about 50 pounds a day.

(Morris Cohn, *Editor, Munic. Sanitation.*) An experience with seeding a small septic tank in the country, in which 50 gallons of Schenectady sludge was to be used,

was cited. A drum of the sludge stood over a hot week-end with bung of the drum closed. So great a pressure developed that the drum swelled to a spherical shape. The fun came when someone had to ease out the screwed in bung-plug. The threads let go and he (Cohn) was the one needing renovation.

*Regarding prominence of chemical precipitation—how can sedimentation and coagulation be improved without the use of chemicals? Can pre-aeration help?*

(Frank C. Roe, *The Carborundum Co., Niagara Falls, N. Y.*) Aeration of sewage coagulates solids and gives some grease removal. Twenty to thirty minutes aeration would increase a 50–60 per cent suspended solids removal to 70 to 80 per cent. The B.O.D. reduction will in general parallel the suspended solids removal. If the usual removal is 35 per cent, this may be increased to 60 per cent by the use of air. By this method, Dodge City, Kansas, secures a 60 per cent B.O.D. reduction.

(A. F. Dappert, *N. Y. S. Health Dept., Albany.*) *Is this due to solids removal or to oxidation of the oxygen demand substances?*

(Mr. Roe.) To both.

(E. B. Phelps, *Prof., Columbia Univ.*) He disagrees with this. Careful studies have shown that it is impossible to speed up the oxidation process by blowing air. Oxidation has been shown to be independent of the air present.

(Wm. A. Ryan, *Chemist, Rochester, N. Y.*) At the Brighton, N. Y., plant aeration within the flow chamber of Imhoff tanks adds to the odor problem. It coagulates colloidal matter in the sewage but adds to the load on the trickling filter. With such aeration, activated carbon has been needed for odor control. The coagulated colloids do not settle well.

(F. C. Roe.) About odors: The Washington plant has adopted pre-aeration to reduce odors. When sewage is fresh, aeration will maintain its freshness.

(H. W. Taylor, *Cons. Eng., N. Y. C.*) Has used post aeration to maintain oxygen content of sewage plant effluent.

(L. H. Enslow.) With reference to Mr. Ryan's use of aeration: This cannot be successfully employed in the flow-through chamber of the Imhoff tank. Separation of the contents of digestion compartment and liquid above the slots is none too good in this type of tank, and upward currents caused by this method of aeration result in seeding with fresh sulphide producing organisms from below. Now, by having a separate pre-aeration tank and no return sludge the method may be used to some advantage, provided the air is sufficient to keep the sewage from going septic.

(Joe Gilbert, *Link Belt Co.*) Lakewood, N. J., secured a 20 per cent reduction in solids by using paddle mixing and without the use of chemicals.

(Morris Cohn.) It has been shown that solids may coagulate by shaking a sample of sewage. Cited evidence from Prof. Phelps.

(E. B. Phelps.) A simple experiment carried out by repeated daily shaking of a sample of sewage in a bottle showed that mechanical impinging of particles produced a decided flocculation effect. Long-continued, the effect had been gradual purification of the sample.

(L. H. Enslow.) At San Francisco, a 30-minute mixing period in paddle equipped tanks had been found equivalent to a large amount of chemicals. Such mixing was expected to be used continuously and chemicals saved until necessary to secure additional purification through raising the flocculation effect.

*At Ithaca, N. Y., there is only one sludge digestion tank, 20 ft. deep by 50 ft. in diameter. About once yearly the level of the liquid drops suddenly about 3 ft. The tank is about three quarters above ground, and apparently is tight. How can this be accounted for?*

(W. W. Watkins, *Oneonta.*) Is there any increase in gas at the time the drop takes place? At Oneonta, this happens when there is agitation or when drawing sludge. He believes it is due to release of confined gas in the liquid and sludge.

(Chas. Agar.) A conversation with Prof. Walker, Cornell University, Ithaca, brought out the fact that it is probably a scum problem. Gas pockets under the scum might cause the loss of liquid level.

(Ogden Kerr, *Operator, Ithaca.*) Sludge is pumped at Ithaca twice daily now and scum trouble is not as great as previously.

*What legal action can be taken to secure compliance of laws forbidding pollution by industrial waste?*

(A. F. Dappert.) Pollution may be of two kinds: (1) Industrial waste alone; (2) Industrial waste with sewage. There is a state health law requiring the submission of plans for application to dispose of waste. If no permit is obtained by the industry there is a penalty if stream pollution is started. When industrial waste is mixed with sewage the State law covering this condition states that the discharge of quantities injurious to public health is forbidden. The Commissioner notifies the municipality or industry concerned with a notice to show why an order to discontinue should not be issued. This order if approved by both Attorney General and Governor becomes valid. It has been applied in only two cases. In an action against the City of Buffalo, it was signed, but in the case of Auburn, the order was issued but never signed. Much work is being done in an attempt to have industrial waste treated—from the point of view of education of and co-operation with industry.

*What is the latest and best method of disposing of the supernatant liquor from digesters?*

(F. C. Roe.) This question came up at the last Ohio Conference, and there lagooning or disposal on sand beds seemed the most practical method.

(Louis Illig, *Harlem Valley State Hospital, Wingdale, N. Y.*) At this plant the digester supernatant is returned to the raw sewage.

(L. H. Enslow.) The primary problem is to reduce this supernatant to a minimum volume, regardless of disposal method practiced. Some help is given by concentration of sludge prior to its digestion and the best operated plants concentrate the fresh input of sludge in some manner. This reduces the degree of elutriation through the digesters. There is a toxic effect when supernatant is returned to raw sewage and the less the better. Applying it to sludge beds can be greatly improved by addition of chemicals for most effective dewatering, by floating the solids above the liquid. Lagooning is satisfactory if area is available and if plant location is suitable. The axiom should be: minimum liquid input to digesters means minimum digester disturbance and a minimum supernatant problem.

Unreached questions (17) were read by Mr. Cohn and names of persons assigned to answer were given for the benefit of the members submitting them. The meeting then adjourned to visit the new Geneva Sewage Treatment Plant.

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## INSTRUCTIONS FOR OPERATION OF IMHOFF TANKS

By Tennessee State Department of Public Health

Roy Morton, *Chief Engineer*

In order to obtain satisfactory and effective operation from an Imhoff tank it is necessary that a certain amount of attention be given to it regularly. Such attention will require a comparatively small amount of the operator's time but if this attention is not given, the tank will cease to function properly in a very short time and considerable nuisance will be encountered. It is a disagreeable and expensive task to correct operating troubles when the plant has been neglected. The following instructions are prepared to guide the attendant in operating the tank and if faithfully carried out satisfactory results should be obtained.

As there is but one large installation of Imhoff tanks in Tennessee these instructions are prepared specifically for the smaller plants although in general they apply to all installations.

I. *Care of Channels.*—All channels should be kept open and free of solid material, such as grease, scum, grit, etc. Flushing the sides and bottoms with a hose is the best method for doing this. If water under pressure is not available good results may be obtained by scrubbing the channels with a broom or brush.

II. *Care of Flowing-through Chambers.*—1. All floating material, such as matches, sticks, grease, etc., should be skimmed off daily and thrown into the gas vents. Bottles, rags, and other large material should be removed and buried. No scum or decomposing material should be allowed to accumulate in the flowing-through chambers or offensive odors may result.

2. The walls and sloping bottoms should be scraped down with the squeegee at least twice weekly, and the solid material pushed through the slot. Scraping should be done carefully in order that no solid material will be stirred up to pass on through the outlet. In case the squeegee cannot be pushed through the slot it will be necessary to clean the slot by dragging a chain through it, using a saw-like motion. The walls of the flowing-through chambers above the water line should be washed or scrubbed down in order to remove any clinging material. The squeegee may be easily constructed from the attached plan.

III. *Reversing the Flow.*—In some plants provision is made for reversing the flow of sewage through the tank. This is necessary in order to permit even deposition of the sludge and to obtain a sludge of more uniform composition. The flow should be reversed at least once a month and preferably every 15 days.

IV. *Care of Gas Vents.*—At least twice weekly the scum in the gas vents must be broken up with the churner or hose stream if water is available. This is necessary in order that the floating material, which has been raised by gas formed during sludge digestion, may settle to the bottom. If this is not done consistently the scum will accumulate to a depth of several feet, resulting in considerable odor nuisance. It may even be necessary to remove the material from the tank and bury it, an expensive and disagreeable process. If water is used for breaking the scum it should be used sparingly and at frequent intervals. If too much water is used at one time some of the solid material will be washed up through the slot, interfering with sedimentation, which results in a poor and offensive effluent. The walls of the gas vents should be washed or scrubbed clean to prevent any decomposing material from clinging to them.

V. *Measurement of Sludge.*—In order that the operator may know the rate at which sludge is being deposited, it is necessary that the depth of sludge be measured at intervals not exceeding two weeks. This may be done by the use of a sounder, constructed of a flat conical pan with a weight at the center. The depth of the sludge may be measured from the top of the tank. In no case should the sludge be allowed to rise higher than within two feet of the slots in the bottom of the flowing-through chamber.

VI. *Removing Sludge.*—Sludge should usually be drawn about once a month when the tank is operating about to capacity. During the winter months it will probably not be necessary to remove sludge unless trouble is experienced or the sludge rises to within two feet of the slot. Well-digested sludge is black and has very little odor. Only this well digested sludge should be removed. It is better to draw a small amount of sludge at frequent intervals than to draw a large amount infrequently. Undigested sludge is gray and none of this material should be drawn. As soon as the first gray color appears no more of the material should be removed. It is necessary that some digested sludge be left in the tank in order to assist digestion of the remainder. Sludge should always be removed slowly or the heavier undigested sludge may be forced out of the tank. The sludge in the riser pipes will sometimes become caked and the material will not flow when the valve is first opened. If the tank is not equipped with water pipes along the bottom for loosening the sludge, flow may be started by rodding the riser pipe or by jetting with a hose fastened to a rod. After sludge has been removed the riser pipe should be filled with water to prevent the sludge from caking.

VII. *General.*—Water under pressure is a very material aid in the operation of this type of tank. Whenever possible a water line should be provided. In some cases a small pressure pump has been used to pump clarified sewage for flushing and cleaning purposes.

The plant should be inclosed within a suitable fence in order to prevent accidents and depredations. Wood covers have not proven satisfactory as they interfere with proper operation.

All valves, gates, and other appurtenances should be tested regularly to see that they are in good operating condition.

Blank forms will be furnished by the State Department of Public Health on which a permanent record of operation may be kept.

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## SUGGESTIONS TO SEWAGE PLANT OPERATORS

By Texas State Department of Health

V. M. Ehlers, *Chief Engineer*

In various sections of the state sewage plant operators have reported considerable trouble with foaming in the Imhoff tanks. As a result, filters are being clogged, odor nuisance occurs, and an inferior effluent is discharged. Foaming in the tank indicates that the process of sludge digestion has been interfered with, caused by any number of factors, one or more of which might be the following:

1. Occasionally mash, milk plant waste, or other acid producing materials may be dumped into the sewer system.
2. The operator may have drawn too much sludge at one time, leaving an insufficient amount of ripe sludge in the tank to seed properly the incoming raw solids.

3. The tank digestion capacity may be too small.
4. Sudden changes of temperature which produce an acid condition in the tank.
5. Unbalanced biological conditions and other unknown factors.

It is possible to overcome some of these adverse conditions by instituting a few changes in the operation attention given the tank. Sometimes, however, if the tank is entirely too small, it may be necessary to add a unit. The following suggestions may improve conditions:

1. Remove the scum from the gas vent, thereby minimizing gas pressure.
2. Add dilution water, stirring the sludge and submerging the scum.
3. Resting the tank.
4. Changing the pH of the tank to 7.2 by the addition of lime. This means an alkaline sludge rather than an acid sludge.
5. Using a simple scum removal device perfected by Edgar Whedbee of Dallas and now in use in a number of cities. The foaming material is removed from the gas vents by the installation of a scum withdrawal pipe. The open upper end is submerged in the scum, a plunger plug is inserted below the horizontal discharge line, the valve is opened and scum flows through the outlet pipe by gravity. This material is then placed on drying beds. The sludge beds may be utilized for this purpose. In designing new plants, provisions should be made for scum removal and scum drying.

If daily attention is given to the sewage treatment plants, a great many of the difficulties of operation may be anticipated and prevented.

# Editorial

## ACTIVATED SLUDGE IN AMERICA AND ABROAD

The description of the West Middlesex plant in this issue, page 111, draws attention to the culmination of two decades of activated sludge development in England. Before the completion of this plant, the largest diffused-air activated sludge plant in Great Britain was the new Manchester plant (Davyhulme), described in this journal, page 765, July, 1935. The Davyhulme and West Middlesex plants are representative of the most advanced design of air-diffusion plants in England. In America there are a number of large plants which typify the usual American practice in design of activated sludge works. These plants include Indianapolis, Milwaukee, Chicago North Side, Cleveland Easterly, Chicago Calumet, Ward's Island (New York), and Chicago Southwest Side. On the whole, the differences between the English and American type of plant are not great, but apparently there has been a progressive development in America toward design of large units which has tended to decrease the cost, without loss of efficiency. The earlier American plants included aeration tanks 15 ft. deep and 15 ft. wide, but in more recent design greater widths of channels are being used, for example, 34 ft. at the Calumet Works and 32 ft. at the Southwestside Works. The English plants have not as yet exceeded a width of 15 feet. American plants seem to be designed for aeration alone, whereas in England re-aeration of sludge is usually included. It is surprising that English engineers have provided re-aeration in view of the long aeration periods customary in that country. It may be that this practice follows the precedent of experience at Birmingham, where re-aeration was shown to be of value, with partial aeration for very short periods of one hour or less. Just why this should be carried over into complete treatment plants with aeration periods of 8 to 12 hours is difficult to understand. Practically all experience in the United States has failed to show any clear-cut benefits from re-aeration. These conclusions have also been reached in large-scale experimental work in Germany.

Another major difference between the large English and American plants is the provision for thorough pre-sedimentation in English plants, where the settling periods range from 1 to 4 hours, whereas in America 15 minutes to 1 hour is considered sufficient. A very puzzling feature of design in the West Middlesex plant is the provision of two stages of preliminary settling, as described on page 112 of this issue. The first stage, in circular settling tanks, undoubtedly removes a large proportion of the settleable solids; the second stage, with rectangular tanks and Mieder sludge scrapers, must settle only the suspended solids of very low specific gravity, possibly difficult to be removed by the Mieder-type scraper. It would be of interest if the designer would explain why two stages and two types of tanks were used for preliminary settling. With weak American sewages, for example the North Side at Chicago, it has been found that practically no difference in air consumption can be demonstrated whether the sewage is pre-settled or not. It must be remembered that this sewage is comparatively weak and the concentration of solids in the aeration tank is maintained at a low average amount.

Final settling tanks in England are usually small, resulting in a large number of units, such as the 40 tanks at West Middlesex, each only 60 ft. in diameter. The settling tanks at the Chicago-Southwest Side are 125 ft. in diameter. In American design the settling rates of final tanks have been pushed to higher rates than in England, but increased capacity has not been reached by any rule-of-thumb procedure but is based on study of a large amount of data from the various American plants in which mechanically cleaned final settling tanks have been used.

In the disposal of solids English plants have followed precedent to a large extent, although the efficient use of digestion gas on a large scale has reached tremendous proportions at the West Middlesex plant. In America the Cleveland Easterly Works will include digestion and utilization of gas, but the other American plants mentioned use

different procedures such as: fertilizer production at Milwaukee; incineration or fertilizer production at Chicago Calumet and Southwest Side; and, tentatively disposal at sea for Ward's Island. The Milwaukee plant now has a long record of operating experience in disposal of sludge as fertilizer and with the improved economic conditions the procedure makes a much better showing than during the depression years. There does not seem to be a standard or stereotyped formula for sludge disposal in America but, of course, this is also true of the West Middlesex plant, where sludge disposal in many respects is similar to American procedure in smaller activated sludge plants. Mr. Watson has had long years of experience in two-stage digestion at Birmingham and his adoption of two stages at West Middlesex, including heat and gas collection in the first stage, is based on a wealth of experience and good judgment.

Activated sludge in Germany and on the Continent has not reached the large scale of development found in England and the United States. The Essen Rellinghausen plant is still outstanding in Germany although it is only a small unit. Some large-scale development has occurred at Berlin and possibly the process will be utilized there if the current interest in utilization of sewage for land sprinkling does not run away with the good judgment of the German engineers. Most of the developments in Germany have related to details of design of small units. The paddle wheels at Essen Rellinghausen have not been used widely although there is a plant of this type at Helsingfors, Finland, and there are several in the United States, including Phoenix, Arizona, and Muskegon Heights, Michigan. In Germany the use of biological surfaces has intrigued the thoughts of investigators, but the experimental work has not resulted in any large-scale development.

In Holland, Dr. Kessener has developed types of mechanical aeration for small plants which are quite ingenious and in his writings he shows a profound grasp of the fundamental principles of the activated sludge process. Notwithstanding the few and small activated sludge plants in the Netherlands, Dr. Kessener must be considered one of the foremost practitioners of modern activated sludge treatment in the world.

Mechanical aeration has, of course, had a long history of development, particularly in England. The Haworth system of channels has reached its greatest development at Sheffield and this scheme has also interested the French and Japanese. It has had no development whatever in America. The Simplex type of aeration has spread over the world but mainly in medium or small plants, except in Japan and England. There are many prototypes of the Simplex mechanical aerator, particularly within the past few years in America. Undoubtedly this type of aeration appeals to the inventive genius of engineers and we may expect more general use of these plants for small communities. Various types of activated sludge plants have been studied in Italy and Russia although no large activated sludge plants are now operating in either country. Russia may come forward with considerable development of the activated sludge process. Small plants are operating in India with a larger plant recently completed at Bombay.

As one surveys this far-flung area of activated sludge plants it is apparent that the process is universally relied on as a practical method of treatment from the smallest to the largest works. In the large plants there is comparatively little variation in type of design and no profound changes have occurred for the past ten years. It is a tribute to the plants now eight or ten years old, such as the Indianapolis, Milwaukee and Chicago plants, that no radical changes have occurred in the more recent design of super activated sludge plants, such as those at Ward's Island and Chicago-Southwest Side. The record of development by American engineers has been sound and design of plants has been shown to be based initially on good engineering and good economics.

F. W. M.

# Reviews and Abstracts

H. W. STREETER

## ENGLAND'S GREATEST ACTIVATED SLUDGE PLANT
## WEST MIDDLESEX MAIN DRAINAGE SCHEME
## MOGDEN WORKS

JOHN D. WATSON, *Chief Engineer*

Memorial Program for the Inauguration of the Works by the Right Honorable Sir Kingsley Wood, M.P., Minister of Health, October 12, 1936.

Reviewed by F. W. Mohlman

The Mogden Works of the West Middlesex Main Drainage Scheme was officially inaugurated by formal ceremony October 12, 1936. This great activated sludge plant is by far the largest in the British Empire, and is exceeded in size and cost only by the Southwest-West Side Works of the Sanitary District of Chicago. The Mogden plant has been under construction for the past five years. A description of the scheme was published in *This Journal* in November, 1933, page 1055. Details of design have not been published but it is reported that a technical description of the design will be presented by Mr. David Watson, son and partner of John D. Watson, the chief consulting engineer, at a meeting of the Institution of Civil Engineers in February, 1937.

The West Middlesex district lies west of London on the Thames River. It comprises an area of 160 sq. miles, with a population of 771,000 in 1931 and estimated at 1,075,000 at the present time. It is expected that the population will reach 1,250,000 in 1940. The district embraces 16 local authorities, which were served by 28 separate sewage works prior to the concentration at the new plant.

A Parliamentary grant for the works of £4,290,000 was made in 1931. It was stipulated that 90 per cent of the men employed on the works should be obtained through the employment exchange, 70 per cent of whom should be drawn from distressed areas. The cost of the total project was estimated at £5,250,000, divided into £3,250,000 for main sewerage and £1,287,000 for sewage purification and sludge disposal works for a population of 750,000. Because of an unexpectedly rapid rate of increase of population in this area, the plant capacity was enlarged to 1,250,000 and the sewers to 2,000,000, estimated to be the ultimate population of the district. The total capital expenditure is therefore now placed at £5,500,000.

Sewage was first run into the treatment works Dec. 14, 1935, and after a pilot run of the new works the program of main diversion from the existing systems was successfully carried out between February and May, 1936, since when the new plant has been in continuous operation.

### MAIN SEWERAGE

The sewerage system has been designed to deliver a total flow of 690,000,000 U. S. gallons per day to the treatment works, with a dry weather flow estimated at one-sixth this amount, or approximately 115 m.g.d. The dry-weather flow at the start of operation was found to be approximately 48 m.g.d. from a population of a little more than one million.

The sewers range from 21 in. to 12 ft. 9 in. in diameter and the total length is 67 miles (Fig. 1). About 75 per cent of the flow is conveyed by gravity and the remaining 25 per cent is pumped through a riser 50 ft. to the treatment works at Mogden. All flows discharging into the main sewerage system are measured by gauging flumes.

The sewerage construction totalled 1,100,000 cu. yd. of excavation and 375,000 cu. yd. of concrete. The materials included some 75,000 tons of Portland cement, 35 million bricks, 45,000 tons of cast iron and 10,000 tons of steel.

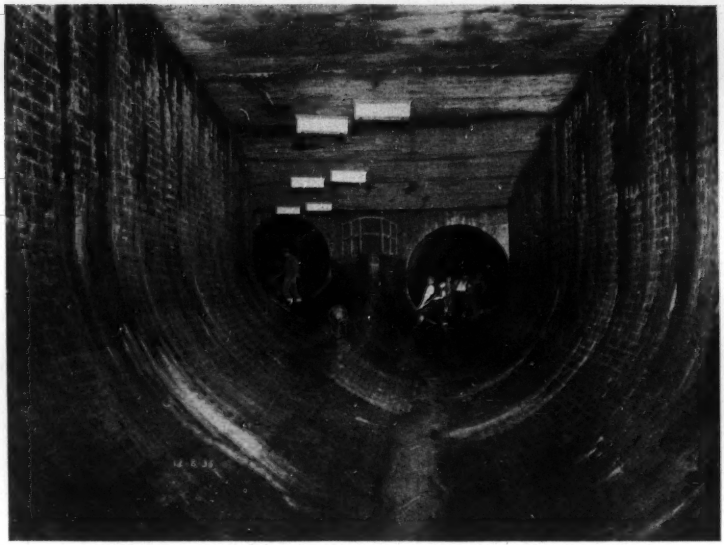

FIG. 1.—Junction chamber, 9 ft., 10 ft. 9 in. and 12 ft. 9 in. sewers.

## MOGDEN PURIFICATION WORKS

The treatment works now occupy an area of 45 acres out of 70 reserved for ultimate requirements. The various steps in the treatment comprise screening, grit removal, preliminary settling in two stages, aeration with activated sludge, final sedimentation and discharge of effluent through multiple outlets (Figs. 2 and 3). Storm water tanks are provided for settling only of flows in excess of three times and up to six times the dry weather flow. Sludge is digested in primary heated digesters at the Mogden Works, thereafter pumped to the Perry Oaks site for further digestion in open tanks. The digested sludge is dewatered on open-air sand beds. Gas collected at Mogden is used for power production in gas engines, whose cooling water is circulated through coils in the digestion tanks to heat the sludge.

*Screening and Grit Removal.*—There are six units of coarse screens, each with a capacity of 114 m.g.d. Each unit is equipped with a hand-cleaned coarse rack with bars 4 in. apart, followed by a mechanically cleaned bar screen with bar spacings of ¾ in. The screenings are transported by belt conveyor to the disintegrator plant, where they are macerated and discharged back into the sewage.

There are six grit chambers each 90 ft. long. The detention period is 1.5 minutes at the designed flow of 1 ft. per second. The grit is removed by suction dredging and, after further washing, is pumped to settling ponds for disposal. Flows from the grit chamber in excess of three times the dry-weather flow are treated in the storm water tanks.

*Primary Sedimentation.*—Sewage flows up to 3 times d.w.f. are settled in two stages prior to aeration. There are first 8 circular tanks, each 95 ft. in diameter and 12 ft. deep, with a total capacity of 5,400,000 gallons. The sludge is removed by "an electrically operated revolving bridge type mechanism." (With the design d.w.f. of 115 m.g.d., the total displacement will be approximately 1.1 hr.) Following the circular

tanks is a battery of 4 rectangular tanks, each 200 ft. long by 150 ft. wide by 12 ft. deep, with a total capacity of 10.8 m.g., giving twice the settling period of the circular tanks. A Mieder-type single scraper is used to sweep the sludge to hoppers at one end of the tanks, whence it is removed by hydrostatic head. Each tank is divided by a longitudinal baffle, making a width of 75 ft. to be spanned by the Mieder scraper.

*Stormwater Tanks.*—Flows over 345 m.g.d. are diverted to the 8 stormwater tanks, each 230 ft. long by 150 ft. wide and 12 ft. deep, with a total capacity of 24 m.g. A Mieder-type scraper is used for removal of sludge.

*Aeration Tanks.*—There are two batteries of aeration tanks, each battery containing six units. Each unit consists of 4 channels, 400 ft. long, 15 ft. wide and 12 ft. deep. The total capacity is 24 m.g. One battery is designed on the "spiral-flow" basis, with two rows of 8-in. diffusers on one side of each channel, while the other is arranged on the "longitudinal ridge-and-furrow" principle, with three rows of 6-in. diffusers spaced at 5-ft. centers. Four of the aeration tanks can be used for reaeration of sludge.

*Final Settling Tanks.*—The mixed liquor from the aeration tanks is settled in 40 final settling tanks, each 60 ft. in diameter and with a total capacity of 12 m.g. The upward velocity will not exceed 7.5 ft. per hour. Sludge is removed by a rotating ring-type mechanism. Provision has been made for returning 15 to 50 per cent of sludge, based on the sewage flow. Waste activated sludge can be returned to the inlet of the primary tanks or pumped directly to the digestion tanks.

The final effluent is discharged into the Thames through twin 11-ft. conduits, terminating in twelve 6-ft. outlets spread over a length of about 400 yards. Effluent can be passed through the stormwater tanks, if desired, before discharge.

*Supplementary Construction.*—Three additional units of aeration tanks and 12 final tanks are now being added, because of the unexpectedly rapid increase of tributary population.

## Sludge Disposal

*Primary Digestion.*—All sludge is combined and pumped to two thickening tanks, each 35 ft. in diameter with 20 ft. water depth. The thickened sludge is digested in twelve circular digestion tanks, each 70 ft. in diameter, with a total capacity of 12 m.g. Four tanks, each having a side depth of 32 ft. and a center depth of 34 ft., are equipped with stirring mechanisms and have fixed roofs (Fig. 4). The remaining eight tanks, each having a side water depth of 32 ft. and a center depth of 51 ft., are provided with gas holders of the spiral carriage type, with a total capacity of 250,000 cu. ft.

*Secondary Digestion and Dewatering.*—The sludge, after remaining in this stage of digestion for about a month, is pumped through a 12-in. pressure line (in duplicate) 7 miles to the Perry Oaks site for final digestion and drying. This plant covers 240 acres.

The partially digested sludge from Mogden is delivered to a battery of 10 circular tanks, each 100 ft. in diameter, 30 ft. deep at the side and 34 ft. at the center, without mechanism or covers. The total capacity is 18 m.g. (Fig. 5).

Sludge is dewatered on 50 acres of sludge-drying beds, divided into 62 plots of approximately 4,000 sq. yd. each. These beds are formed of sand and gravel obtained from the site. The beds are 18 in. deep, graded from 2-in. coarse gravel at the bottom to a layer of sand at the top. Dried sludge is removed by hand. The beds are underdrained and the sludge liquor is returned to the Mogden Works for treatment. The entire site is encircled by an impervious wall of puddle clay, to prevent risk of contamination of the sub-soil water.

*Gas Collection and Utilization.*—The twelve primary digestion tanks are expected to collect about 800,000 cu. ft. per day of gas with a calorific value of 650 B.T.U. This is used for operation of 10 gas engines, 6 direct connected to blowers, and 4 to generators (Fig. 6). The waste heat from these engines is used to maintain a temperature of 80° F. in the digestion tanks. The 10 engines are convertible to Diesel operation. Each is rated at 550 h.p. on gas and 650 on oil.

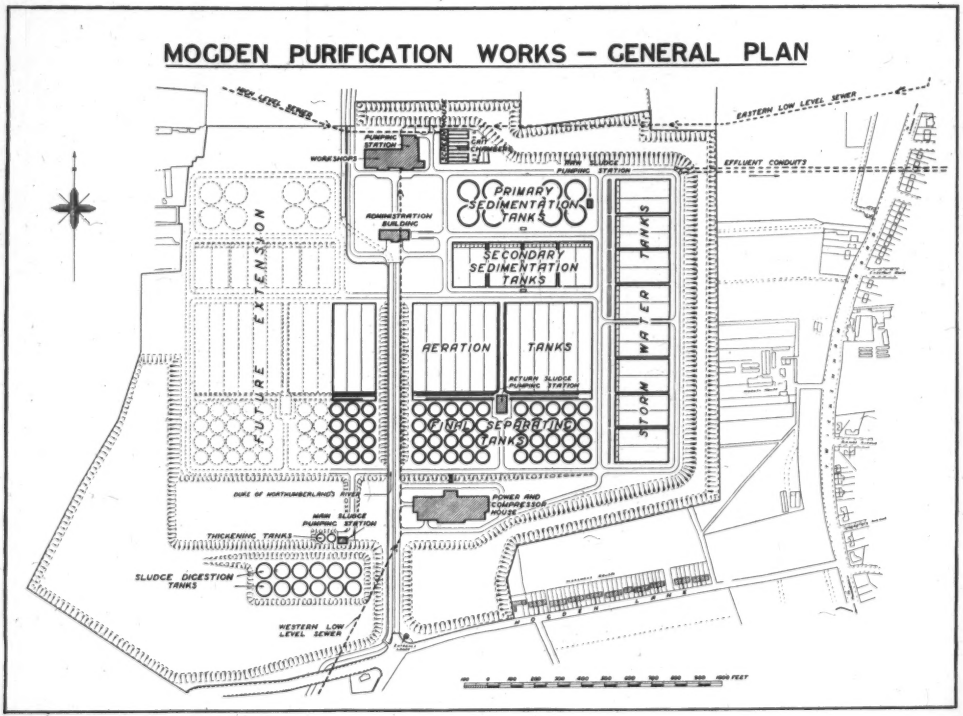


FIG. 2.—General plan.

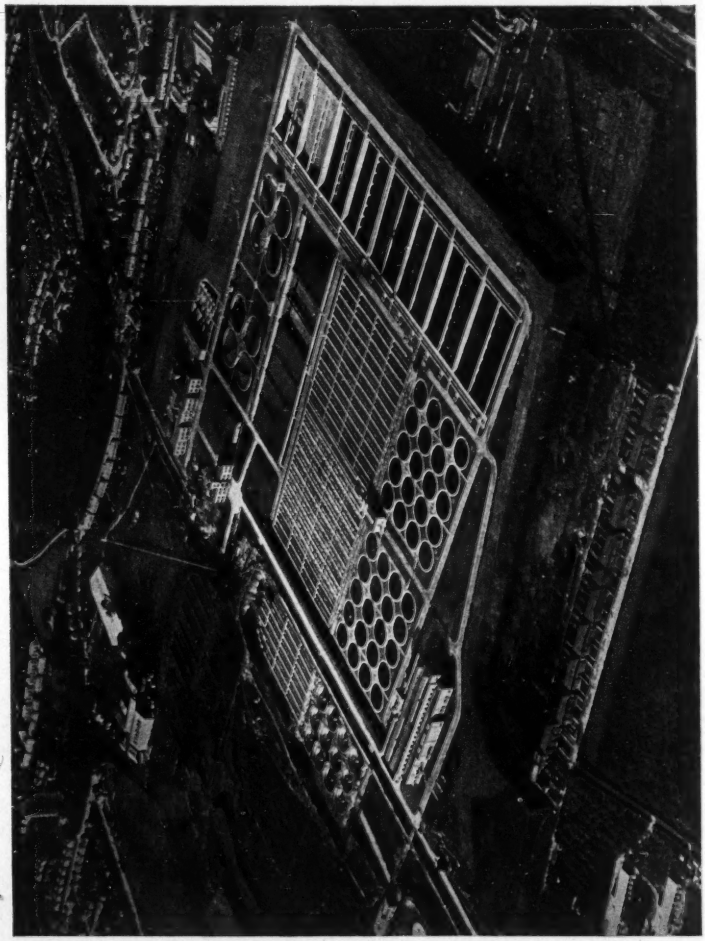

FIG. 3.—Aerial view.

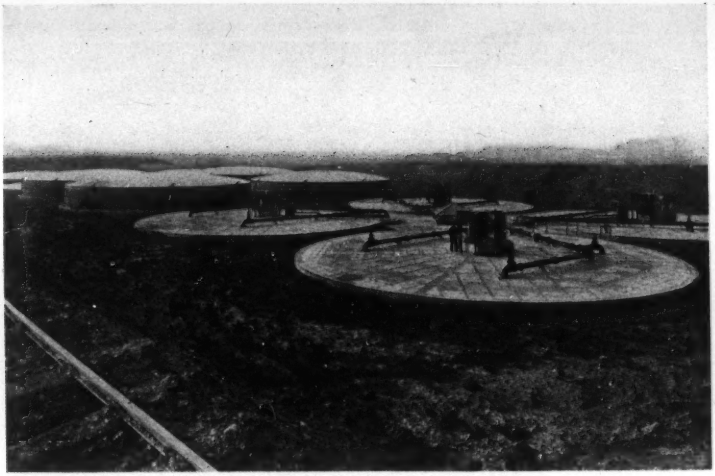

FIG. 4.—Sludge digestion and gas collecting plant.

FIG. 5.—Perry Oaks sludge disposal works.

Each of the 6 blowers has a capacity of 12,500 cu. ft. of air per minute at 7 lb. per sq. in. pressure. The generators produce direct current at 460 volts, used for pumping sewage and sludge, lighting, and for miscellaneous purposes.

The sludge gas is expected to produce 15 million h.p.hr. per year, estimated worth at least £20,000.

*Pumping.*—Sewage is pumped by 12 vertical-shaft centrifugal pumps, 6 of 5000 g.p.m. each, driven by electric motors of 160 h.p., the remaining 6 for stormwater duty, each with a capacity of 18,000 g.p.m., driven by Diesel engines of 500 h.p. each.

*Construction Details.*—The construction of the sewage works comprised 2,250,000 cu. yd. of excavation and 225,000 cu. yd. of concrete. Materials used included some 350,000 tons of sand and gravel, 45,000 tons of Portland cement, 8000 tons of steel, 4000 tons of steel and 3 million bricks.

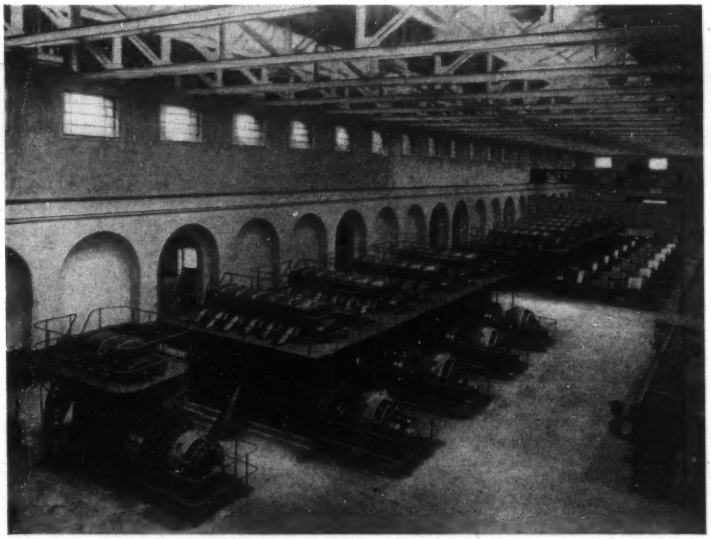

FIG. 6.—Power and compressor house.

*Administration.*—The plant is operated under the direction of C. B. Townend, Engineer-in-charge, who was one of the chief engineers of design under John D. Watson and D. M. Watson, the consulting engineers. The plant chemist is Wm. T. Lockett, formerly of Manchester, and well-known for his pioneer work on activated sludge. The administrative organization has been incorporated in the department of the county engineer, Major W. H. Morgan.

## OPERATING DATA

Mr. Lockett has summarized results of chemical analyses for the period June 1, 1936 to October 31, 1936 (*Cont. Record. and Mun. Eng.*, Dec. 9, 1935, page 1452):

*Results of Treatment at Mogden*

Parts per Million

| Determination | Raw Sewage | Settled Effluent | Act. Sl. Effluent | Final Eff. to Thames |
|---|---|---|---|---|
| 4-hr. Oxygen Absorbed | 85.8 | 48.6 | 9.9 | 10.1 |
| Ammonia Nitrogen | 40.8 | 41.3 | 5.8 | 6.1 |
| Albuminoid Nitrogen | 9.5 | 4.8 | 0.8 | 0.85 |
| Nitrous Nitrogen | — | — | 3.4 | 3.3 |
| Nitric Nitrogen | — | — | 18.5 | 18.3 |
| Chloride as Chlorine | 114 | 116 | 111 | 110 |
| 5-day B.O.D. at 18.3° C. | 357 | 203 | 7.7 | 8.5 |
| Suspended Solids | 307 | 86 | 8.5 | 10 |
| Putrescibility | — | — | 0/149 | 0/151 |

These results indicate that the plant has turned out an excellent effluent, with reductions of 98 per cent of the B.O.D. and 97 per cent of the suspended solids. As these results were obtained with less than half-capacity loading, it would be of interest to have the accompanying operating data, such as aeration period, cu. ft. of air per gallon, per cent return sludge and suspended solids in the aeration tanks. It is gratifying to know that the operation of the plant is in such competent hands. The entire project is a fitting climax to the long and distinguished career of John D. Watson.

## TEXTILE WASTE TREATMENT AND RECOVERY

By J. C. Geyer and W. A. Perry

*The Textile Foundation, Inc.*, 118 pp., $1.00

*Stream Purity.*—Damage to stream purity is not so much a factor of the total quantity of waste in gallons but rather of the quantity and character of the impurities carried by the waste water. Silt and sludge bank forming substances, strong acids and bases, greases and oils, toxic materials, organic dyes and putreseible organic compounds frequently cause damage. Inorganic reducing compounds are sometimes present and combine directly with dissolved oxygen, giving an immediate chemical oxygen demand which largely nullifies the value of the B.O.D. test, and may deplete the dissolved oxygen in a stream. In a growing industrial area the probability of future treatment of wastes made necessary by increasing pollution from other sources must be considered in planning the factory layout.

Danger to public health from textile wastes is negligible, unless sewage from the factory toilets is included, with the exception of wool-scouring wastes which may contain anthrax spores. The destruction of stream life, increased costs of water purification, and damage to boats and structures may present very great and unnecessary economic losses. The loss of pleasures in life through the destruction of natural beauty of streams cannot be estimated in terms of money but it is a real loss, especially when the surroundings are otherwise scenically beautiful.

Standards of stream purity have frequently, and quite properly, been based on a classification of streams into general groups depending upon the requirements of certain users of the stream waters. Although flexibility of operation is necessary, these classifications give the manufacturer a definite idea of the treatment he may expect to give the wastes from his mill, and should be of material assistance in selecting new factory sites. Definite standards of purity for treated textile waste effluents should not be adopted, as textile wastes which require no treatment in one place may require very complete treatment in another. Each manufacturer who is discharging wastes into a stream that might in the future need to be controlled, should collect information which will help him in solving his own problems, and which will protect him from unreasonable requirements or litigation.

*Textile Processes and Wastes.*—Wastes produced in the deturging of the raw material carry more polluting matter than any other wastes produced by the textile industry. An average analysis of wool-scouring waste may show 9000 p.p.m. of grease, 12,000 p.p.m. suspended matter, 55,000 p.p.m. B.O.D., and 7000 p.p.m. alkalinity. They vary widely, however, depending on the source of the raw wool. Prior to scouring, much of the pollution load may be removed from the raw wool by grease extraction with naphtha, and dust removal by beating, or if the wool is refrigerated to — 35° F., both are largely removed as a dust by beating. Grease (lanolin) recovery is commonly practiced by a variety of methods which concentrate the grease by sedimentation (acid method), evaporation or centrifuging. Recovery of potassium salts by evaporation, as practiced during the war, is not now economically feasible.

Cotton kiering (raw wash) may give an average of 1.5 to 2 pounds of B.O.D. and 20 pounds of total solids per 100 pounds of goods produced. The waste is highly caustic.

Silk degumming, or "boiling out" may produce 7 pounds of B.O.D. per 100 pounds of goods in 850 gallons of waste, largely consisting of sericin (silk gum) and spent soap. Flax retting, usually done on the farms, may release 217 pounds of B.O.D. per ton of straw. It is not important in the United States.

Dye wastes vary so widely that classification or general statements are difficult. They are highly colored, however, may contain reducing substances, may be highly toxic, and may have a quite high B.O.D.

*Treatment.*—Reduction of waste within the factory and recovery of waste products should be investigated before attempting to treat the wastes. It is frequently possible to use the wash water from one operation in making up the baths for another. Use of counter flow action and careful temperature control result in efficient use of chemicals and give less waste. There are instances where recovery is practiced on certain dyes, tin salts from silk weighting, caustic soda, sodium ferrocyanide, waste heat, arsenic and sericin.

Frequently, as much as 75 per cent of the textile wastes consist of relatively clean wash water which may be discharged directly into the stream without injury. Plans for separating the dilute wastes from the concentrated ones should be considered in building a mill. The wastes must be equalized in a large holding tank to obtain the benefits of co-precipitation and to level out extreme variations in composition. Screening or aeration may be desirable with some wastes. Chemical precipitation, and pH correction, have been used, followed, if necessary, by filtration, or by secondary biological treatment for a higher degree of purification. There are also a wide variety of methods applicable to the treatment of individual wastes produced from a single operation. Batch treatment and sedimentation is economical for small plants and continuous flow for large ones.

The problem of whether trade wastes should be admitted to municipal and Sanitary District sewers must be decided for each individual case. The legal aspects of equable distribution of costs are difficult to settle and the effect of such wastes on the sewage treatment processes may vary widely. Equalization of flows and pretreatment, either by the individual manufacturer or jointly by a group of manufacturers, may be necessary.

Fifteen treatment plants are described. Seven of these are municipal plants with as much as ¾ of the total flow consisting of textile mill wastes. There are appended to the report: a schedule of State laws governing stream pollution, sample data sheets used in the surveys, a tabulation of chemicals used, and an excellent bibliography of 340 references.

R. W. KEHR

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## INDUSTRIAL WASTES IN NEW JERSEY

BY WILLEM RUDOLFS AND LLOYD R. SETTER

New Jersey Agricultural Experiment Station, *Bulletin* 610, November, 1936

A survey of industrial wastes in northern New Jersey was made with the aid of a number of chemists and engineers employed under the C.W.A. and E.R.A. between December, 1933 and May, 1934. This survey was primarily designed to determine the

volume, strength and character of industrial wastes discharged into the streams of the State, and to determine their comparative importance in relation to domestic wastes.

Industries were grouped in a more or less arbitrary manner, following in general the grouping of the national census. A total of 1792 industrial plants were visited, and definite information concerning wastes was obtained from 1213. The wastes of 401 industrial plants, representative of the various industrial groups, were sampled, and of this number 251 were completely analyzed and 150 partly analyzed for confirmation. Results are reported as minimum, maximum and mean for each type of industry and it is believed that with the number of industrial plants inspected and the care used to select representatives of each type for sampling, the mean results give an indication of what can be expected from individual industries. Tables of results are given for total solids, total suspended solids, settleable solids, non-settleable suspended solids, oxygen consumed and pH for the various types of waste as well as some other results. (Abstractor's Note: There are apparently several discrepancies in some of these tables, as for instance the mean total suspended solids on the dry basis for the steel pickling industry are reported as 2065 p.p.m., the mean settleable solids 8290 p.p.m., and the mean non-settleable suspended solids 1380 p.p.m.)

The considerable variation in the pounds of waste per employee-day within a "type" industry necessitated obtaining the geometric mean as a more correct average waste of a particular "type" waste. These results may be interpreted as the "average" daily pounds of waste per employee for any industry, within the group classification, and some of these results are given below:

*Average Pounds of Waste Daily per Employee-Day for Each Type of Industry*

| Industry | Suspended Solids | Settleable Solids | Oxygen Consumed |
|---|---|---|---|
| Tanning | 1.92 | 0.51 | 1.73 |
| Chemical manufacturing | 1.18 | 0.33 | 1.53 |
| Organic | 0.39 | 0.10 | 0.20 |
| Steel pickling | 0.62 | 0.15 | 0.25 |
| Dye | 0.87 | 0.05 | 3.00 |
| Distillery | 29.16 | 4.32 | 31.89 |
| Dairy | 0.92 | 0.03 | 3.03 |
| Laundry | 3.61 | 0.05 | 1.55 |

Using these average figures and the number of employees in the various types of industries in the whole state, an estimate was made of the total industrial waste expressed in tons per day. An estimated population equivalent of the wastes from all industries was computed on the basis of an average oxygen consumed value of 0.068 pound per

*Oxygen Demand and Suspended Solids of Waste Produced per Employee of Various Types of Industries on the Basis of Domestic Sewage*

(Domestic Sewage equals 1)

| Industry | Oxygen Demand | Suspended Solids |
|---|---|---|
| Tannery | 25.3 | 12.0 |
| Chemical manufacturing | 22.5 | 7.4 |
| Organic | 2.9 | 2.4 |
| Steel pickling | 3.6 | 3.8 |
| Dye | 44.2 | 5.4 |
| Laundry | 22.8 | 22.2 |
| Distillery | 470.0 | 181.0 |
| Dairy | 44.6 | 5.7 |

capita per day. This population equivalent was found to be over 3,000,000, or two-thirds of the total domestic population.

A comparison was made of the oxygen demand and the suspended solids produced per employee by the different industrial groups with the oxygen demand and the suspended solids produced per person as domestic sewage. These results show that distillery waste requires 470 times more oxygen and contains 181 times more suspended solids per employee than the water-carried household wastes of the ordinary individual.

These figures show best the relative importance of the liquid waste for equal numbers of employees and likewise that of industrial waste and domestic sewage in stream pollution problems in an industrial region.

R. S. SMITH

## TREATMENT OF DILUTED SEWAGE BY BIO-AERATION IN THE PRESENCE OF NITRIC AND NITROUS NITROGEN

BY J. H. KERSHAW AND J. W. FINCH

*The Surveyor*, 90, 533–534 (November 6, 1936). Discussed in *The Surveyor*, 90, 565–568 (November 13, 1936)

Sewage treatment at Rotherham consists of primary sedimentation followed by secondary treatment of two types: bio-aeration (activated sludge) and trickling filter. Both units, treating the same settled sewage, were loaded to capacity, largely due to the tendency of the bio-aeration plant to bulk when its loading was heavy, necessitating frequent periods of reconditioning the sludge. Under a new scheme of operation, about 2/3 of the settled sewage goes directly to the bio-aeration tank while the remainder is passed through the trickling filter, secondary sedimentation tanks and thence to the bio-aeration tank.

Improvement in the condition of sludge in the bio-aeration plant was remarkable. Bulking of the sludge stopped, dissolved oxygen in the effluent, based on a 6 months' average, increased from 0.86 to 1.52, the settling characteristics of the sludge improved, it being more granular in nature, while the plant treated 48 per cent more settled sewage. Indirect beneficial effects noted were the more complete treatment given to the portion of the trickling filter effluent used, and an improvement in the condition of the trickling filters under lighter loading, thus giving 30 to 40 per cent better over-all purification for the whole treatment plant.

"The explanation of the ability of the bio-aeration plant to treat more primary settlement tank effluent when diluted with filter effluent is not obvious, and in itself offers much food for thought and material for research." Operating results for two 6-months' periods, one prior to and the other subsequent to adding filter effluent, were as follows:

*Statistics for Rotherham Works During the Present Method of Working*

| Month | Sew. Oxy. | Aeration Units m.g.d. | Units Oxy. | Tank Eff. m.g.d. | T.E. Oxy. | Filt. Eff. m.g.d. | F.E. Oxy. | F.E. Nit. N. | Outfall Oxy. |
|---|---|---|---|---|---|---|---|---|---|
| Jan. | 6.45 | 70.954 | .70 | 55.000 | 3.67 | 15.954 | 1.06 | 1.706 | .82 |
| Feb. | 6.92 | 67.610 | .79 | 52.000 | 4.15 | 15.610 | 1.10 | 1.572 | .80 |
| March | 7.13 | 67.479 | .79 | 45.000 | 4.09 | 22.479 | 1.14 | 1.606 | .82 |
| April | 8.46 | 54.632 | .82 | 31.000 | 5.64 | 23.632 | 1.45 | 1.663 | .91 |
| May | 10.70 | 47.931 | .89 | 29.000 | 7.00 | 18.931 | 1.77 | 1.869 | .95 |
| June | 9.75 | 53.090 | .78 | 36.000 | 6.06 | 17.090 | 1.59 | 1.888 | .86 |
| Average | 8.23 | 60.283 | .79 | 41.333 | 5.10 | 18.949 | 1.35 | — | .86 |
| Totals | — | 361.696 | — | 248.000 | — | 113.696 | — | — | — |

*Statistics for Rotherham Works Previous to the New Working Conditions*

| Month | Sew. Oxy. | Aeration Units m.g.d. | Units Oxy. | Tank Eff. m.g.d. | T.E. Oxy. | Filt. Eff. Gal. | Outfall Oxy. |
|---|---|---|---|---|---|---|---|
| Jan. | 7.94 | 36.390 | 1.06 | 36.390 | 5.83 | — | 1.44 |
| Feb. | 8.98 | 19.842 | 1.46 | 19.842 | 6.43 | — | 1.57 |
| March | 7.83 | 41.714 | 1.10 | 41.714 | 5.22 | — | 1.48 |
| April | 8.14 | 32.576 | 1.36 | 32.576 | 5.94 | — | 1.46 |
| May | 10.10 | 22.556 | 1.30 | 22.556 | 7.26 | — | 1.55 |
| June | 10.10 | 14.304 | 1.33 | 14.304 | 7.11 | — | 1.80 |
| Average | 8.85 | 27.897 | 1.27 | 27.897 | 6.29 | — | 1.52 |
| Totals | — | 167.382 | — | 167.382 | — | — | — |

Nitrates and nitrites present in the filter effluent when passed through the bio-aeration tank were used up in the oxidation of the extra sedimentation tank effluent. Partial control of the new system of operation was obtained by increasing the load of settled sewage on the bio-aeration tank when traces of nitrous nitrogen appeared in its effluent.

The authors conclude that the finely divided humus present in the trickling filter effluent probably weights the activated sludge, thus making it easier to control.

*Discussion.*—Mr. J. T. Thompson (Leeds) stated that at the Wakefield works and at Johannesburg the process tried at Rotherham had been reversed with satisfactory results in that part of the effluent from the activated sludge plant was passed through trickling filters. He was of the opinion that the active properties of the humus were more likely to be of value than its gravity since humus itself was difficult to settle.

Mr. Lumb (Halifax) suggested that the possibility of using nitrite and nitrate nitrogen be considered in sewage works design.

Mr. A. R. Chadwick (Keighley) emphasized the beneficial effects of dilution as shown by the effect of increased wet weather flows on the operation of a plant treating a sewage high in industrial wastes.

Mr. H. H. Stanbridge (Pudsey) suggested as explanations of the effects noted at Rotherham: (*a*) the dilution effect, (*b*) the oxygen present in the diluent as dissolved oxygen or in the form of nitrites and nitrates. He pointed out that upon entering the bio-aeration tank there was an immediate dilution of the incoming sewage with substrate (plus activated sludge) of fourteen times the sewage volume. Mr. Kershaw stated that the operating costs were no greater under the new system than under the old one. Mr. Stanbridge remarked that at Huddersfield a batch of sludge from the humus tanks was pumped into the aeration tank with a resulting improvement in the condition of the activated sludge. Mr. Kershaw replied that the presence of such large amounts of humus required additional dissolved oxygen, which was none too plentiful in a bio-aeration plant.

Mr. Oliver (Harrogate) believed the improvement due largely to dilution since a similar effect was noted during wet weather flows when nitric and nitrous nitrogen were not present.

Mr. J. M. Wishart (Shipley) wondered if the work done by the bio-aeration unit could not have been accomplished more cheaply with trickling filters. He stated that an experimental activated sludge unit at Shipley was being used to treat trickling filter effluents, equivalent in strength to strong sewage. He believed that the continuous supply of humus gave a "much more healthy and settled sludge."

Dr. H. H. Goldthorpe (Huddersfield) thought the Rotherham bio-aeration channel was probably deficient in oxygen and estimated that the oxygen required for the overall improvement in purification could be roughly accounted for by the decrease in nitrites and nitrates. He thought the total oxygen available from the trickling filter effluent was small in comparison to that obtained from nitrates.

Mr. C. J. Artist (Wakefield) stated that he had found dilution with trickling filter effluent during low flow beneficial to the bio-aeration unit at Wakefield.

R. W. KEHR

## FURTHER STUDIES IN THE TREATMENT OF GASWORKS LIQUORS IN ADMIXTURE WITH SEWAGE

BY A. KEY AND W. ETHERIDGE

*The Surveyor*, 90, 603–5 (November 20, 1936)

In studying the disposal of gasworks liquors by dilution, a series of 1 per cent to .25 per cent dilutions of both sewage and sewage plus gasworks liquors were incubated in tightly stoppered bottles at 18° C. for periods up to 60 days. Changes in the permanganate oxygen absorption (O/A), nitrites and dissolved oxygen (D.O.) were followed. In some tests changes in phenol, catechol, thiocyanate and ammonium carbonate were also followed, these being important constituents of gasworks liquors.

Phenol and catechol were largely oxidized in two days and the D.O. required appeared to be less than the decrease in O/A. Thiocyanate remained unaltered for 8 days but disappeared by the 12th. Ammonium carbonate was not oxidized during the first 9 days. The O/A decreased fairly rapidly during the first two days, then remained relatively constant at a value ½ of the original in the experiments on spent liquor and 1/3 of the original where crude wastes were used. The high O/A residual compared to that obtained when the oxidation took place in trickling filters was explained by residual thiocyanates which are oxidized in trickling filters adapted to treating gas liquors but not in bottles. Concentrations of waste liquor up to 5 per cent of the sewage did not appreciably slow down the purification of the sewage. In the ¼ per cent dilution after 5 days of incubation, the presence of nitrites increased the O/A until it reached 10 parts per 10,000 at 26 days, then both decreased after 29 days until the nitrites disappeared after 54 days. The nitrogenous oxidation was less in the spent liquor, as it contains only fixed ammonia.

To provide a large scale test on the treatment of gas liquors on bacteria beds, gasworks liquors were pumped into the sewers at night and collected at the sewage disposal plant in separate tanks. The bacteria beds were divided into four groups and after a careful check of their condition with regard to sewage purification, one group was retained as a control treating only sewage, another was dosed with sewage plus spent liquor, and a third with crude liquor added to the sewage which was held constant in each case. The admixed wastes were gradually increased in amount up to .25 per cent, then held constant for five weeks, after which the dosage was doubled for a further ten weeks. The ammonia present was almost completely oxidized and the added liquors caused a slight increase in O/A when .25 per cent was added. With .5 per cent added, the O/A of the influent was doubled with the spent liquor and tripled with the ammoniacal liquor, but the effluents showed only about 8 per cent of this increase. The effect of the carbonaceous matter in the liquor on the O/A appeared to be negligible. The 5-day B.O.D. of the effluent appeared to be affected only if the increased waste liquor hindered complete nitrification.

In the treatment of waste liquors with activated sludge, high O/A values ("O/A reversal") were obtained in the effluent coincidently with the presence of nitrites, and in such cases the O/A values gave false pictures of the purification accomplished. If the nitrite had been oxidized to nitrate, "O/A reversal" did not appear. The greatest effect observed when treating sewage containing gasworks liquors was retardation of nitration. This was especially marked with the ammoniacal liquor.

The phenomenon of gas-lifted activated sludge, attributed by O'Shaughnessy and Hewitt to the formation of nitrogen gas from nitrites under certain conditions, occurred also in these experiments but with nitrate instead of nitrite in some instances. When the nitrogen gas was derived from nitrite, it was quantitatively equivalent to about 1½ times the nitrogen in the nitrite destroyed, while with nitrate the nitrogen produced was about equal to that in the nitrate destroyed.

"It has been found that the presence of gas liquor adds greatly to the chlorine demand of sewage as determined by the O-tolidine test. . . ."

R. W. KEHR

## RIVER AND STREAM POLLUTION

BY A. PARKER

*The Surveyor*, 90, 649–650 (November 27, 1936)

Increasing water demand has resulted in depletion of ground waters in some localities and available sources of uncontaminated water, both surface and underground, are gradually being allocated. Any probable future demand can be met, however, if steps are taken to prevent undue pollution of surface waters. Present conditions are far from satisfactory, in that many streams in industrial areas are quite unfit, except after costly treatment, for the purposes for which they are required.

The treatment of sewage, although expensive and capable of improvement, can produce a treated effluent which will not cause undue pollution in most rivers. With regard to trade wastes, however, there is an enormous amount of work ahead before entirely satisfactory methods of treatment can be devised. In addition, new processes and new industries are continually bringing up new problems of trade waste treatment.

Trade wastes may be classified into three main groups: (1) waste water such as those from coal washeries and quarries which contain, largely, nonpolluted suspended matter; (2) those containing both suspended matter and polluting substances in solution such as tanning wastes; (3) those, such as gas wastes, in which the polluting substances are mainly in solution and colloidal suspension. Those wastes in the third group may require both chemical and biological treatment, while less will suffice for the second group, and usually still less for the first group. Disposal into municipal sewers may be possible if the ratio of trade wastes to domestic sewage is small.

Investigations of beet sugar wastes have shown that with very simple treatment most of the waste waters could be reused in factory processes. The remaining wastes are amenable to treatment on trickling filters so that there is no need for undue pollution of rivers from this source. Milk products wastes are under investigation by the Water Pollution Research Board. Much improvement can be effected by eliminating losses of milk and its products into the waste and the treatment of milk wastes by activated sludge or trickling filters, under certain conditions, has been shown by means of large scale tests to be practical.

R. W. KEHR

## INVESTIGATION OF SEWAGE DISPOSAL PROBLEMS

BY J. BOLTON

*The Surveyor*, 90, 635–636 (November 27, 1936)

In his presidential address to the Institute of Sewage Purification, Mr. Joshua Bolton reviewed past attempts of the Institute to inaugurate coordinated research among the various cities on sewage problems. Although many municipalities had indicated willingness to enter into such a scheme, lack of appropriations prevented the carrying of adequate research staffs, the burden fell unequally upon the more willing cities, and there seemed considerable doubt if such money had been spent wisely. He estimated that an adequate central research department could be established and maintained for 1/50th of a penny per £ of taxable wealth,—a central research department such as the gas and electrical industries maintained.

He stated that in response to a request by the Ministry of Health, his city had been screening storm water flows in excess of six times the dry weather flow, such excess being previously permitted to pass untreated to the river. He found a large amount of screenings collected and believed the requirement both reasonable and beneficial to the streams.

R. W. KEHR

## MEASUREMENT OF SEWAGE

*The Surveyor*, **90**, 728 C & D (December 18, 1936)

In a discussion of the measurement of sewage flows at a meeting of the Northwestern Branch of the Institute of Sewage Purification, Mr. F. T. Wilson (Lea Recorder Co.) stated that while it was possible to install weirs ahead of screens, it was undesirable, as there was considerable backing up of sewage and the screens must be operated continuously, cutting the life of screens to about 1/3 that obtained if the screens were worked intermittently.

Mr. C. Jepson (Manchester) stated that at Davyhulme an electrical device, used to maintain a given volume of sewage passing forward to complete treatment, had proven accurate to about plus or minus 2 per cent. The device operated from the recording flow meter, electrically lowering or raising a gate which increased or decreased the flow over a by-pass weir.

Mr. J. P. Todd (Ashton under Lyne) mentioned a method for separating storm water from sewage receiving full treatment by installing a 50-foot weir and making a by-pass or "dead end," thus preventing excessive storm flows going forward to complete treatment.

R. W. KEHR

## SEWAGE TREATMENT AT MANCHESTER

(Abstracted from the Rivers Departments Annual Report.) *The Surveyor*, **90**, 720 (December 18, 1936)

The greatest part of the city sewage is treated at two main works, Davyhulme and Withington. The Withington works consist of two diffused air activated sludge units treating 3 m.g.d., somewhat less than half the total flow, and sedimentation-contact filter treatment for the remainder. The two activated sludge units produced effluents averaging 9.7 and 9.9 p.p.m. B.O.D. with a power cost of £1 14s. 3d. per m.g.

At Davyhulme there is a 16 m.g.d. diffused air activated sludge plant divided into seven sections, two of which return sludge independently without reactivation, the remaining five having a common section for reaeration of the return sludge. There is also a small Simplex plant of 1 m.g.d. capacity and a bioaeration channel plant with a channel section 3′ 6″ deep by 6′ wide by 3700′ long treating about 0.5 m.g.d. The remainder of 32 m.g.d. dry weather flow is treated by sedimentation and contact filtration. Of the three activated sludge systems, the power consumption of the diffused air unit was 35.1 b.h.p. per m.g. with 11 hours' detention and 90 per cent purification, while under the same conditions the Simplex plant required only 30.0 b.p.h., giving, however, less purification. The power consumption for the bioaeration unit was greater than either of the others. "Results show that the greater elasticity of the diffused air plant enabled it to stand up against difficult conditions better than either of the mechanical plants." The construction of activated sludge units to replace the contact beds at Davyhulme is planned. In studies of pretreatment of occasional abnormal sewage prior to activated sludge treatment, it was found that chemical pretreatment consisting of acid and alumino-ferric dosage, mixed by diffused air and settled for brief periods, was both useful and economical. Such treatment in no way hindered the purifying properties of the activated sludge.

R. W. KEHR

## PRODUCTION OF FERTILIZER FROM SEWAGE SLUDGE

*The Surveyor*, **90**, 681 (December 4, 1936)

Mr. R. Anstead emphasized the decreasing availability of humus from such sources as manure and its necessity in soil fertilizing. He advocated compositing sludge and house refuse and the manufacture of fertilizer from it, the economy of the process being justified partly on the basis of national necessity.

Mr. P. G. Lloyd (Kingston) thought that better fertilizer could be produced from sludge alone. Kingston, in the past 40 years, had disposed of all sludge produced, a total of 100,000 tons, at approximately the cost of production. He maintained that the sludge should not be sold for less since it involved the subsidizing of farmers by city taxpayers.

Mr. J. E. Farmer (Croydon) stated that composting of screenings in soil was tried during the war but was discontinued at the end of the war due to odor production and high costs. At present sludge was disposed of at Croydon by returning it to the land to grow crops. High land values and rents made production costs of such crops high, however.

Mr. E. Hodgson (South Norwood) stated that at South Norwood 150 tons of wet sludge were mixed in lagoons beside a railway siding with 100 tons of pulverized house refuse, giving 125 tons of mixture with a moisture content of 50 to 60 per cent. The mixture was sold at a loss but from a national point of view the process was justified since it returned this material to the soil.

R. W. KEHR

## INTERSTATE SANITATION COMPACT AND ITS IMPLICATIONS

BY C. A. HOLMQUIST

*American Journal of Public Health*, **26**, 10, October, 1936, pp. 989–95

The far-reaching and important co-operative effort to control waterways pollution is the Interstate Sanitation Compact drawn up by New York, New Jersey and Connecticut. State and local health departments in these states have long known of the rapidly increasing pollution of tidal waters. Those sewage treatment plants that had been constructed were designed only to give local relief from particularly objectionable conditions. There had been no accepted standards available for use as a guide to the proper degree of treatment required.

Sewage from 12,000,000 persons amounting to over 1,300,000,000 gallons and trade wastes from 100,000 industries are discharged daily into the coastal and harbor waters of this region. Sewage in New York harbor drifts back and forth for days because of tidal action. Extensive dredging operations are required each year to remove putrescible sludge deposits from steamship slips and channels. It has been necessary to close a number of bathing beaches and shellfish beds. Certain areas are devoid of fish life because of the reduction of the dissolved oxygen content of the water.

This seriousness of the pollution problem prompted the calling of a number of conferences, and, as a result Connecticut, New Jersey and New York passed laws creating a temporary Tri-State Treaty Commission that was directed to formulate a treaty between these three states and the Federal government. It was also to state the legislation necessary to make its recommendations effective.

Bills legalizing the Compact have been passed by the Legislatures of New Jersey and of New York, and the Compact was approved by a joint resolution of Congress. As far as Connecticut is concerned it will become effective when that state passes laws identical with those of the other two states. The Interstate Sanitation Commission, comprising members from New York and New Jersey has been organized and is now working.

"The Compact contemplates the elimination of offensive pollution, the making of all beaches in the region safe for bathing and recreational purposes, and the return to shellfish culture of many of the areas now condemned." The area included comprises all of the tidal waters in the Metropolitan District.

The waters have been divided into two general classes: One (Class A) in which the areas are to be used primarily for recreational purposes, shellfish culture and the development of fish life, and the other one (Class B) not to be used primarily for the purposes mentioned above. The standards set for Class A waters are high enough to protect public health and fish life, and if those set for Class B waters are met, visible solids of sewage origin will be removed and there will be no public nuisance or menace to health in those waters.

This is the first time that legal representatives of three states have been able to draw up a compact to abate pollution of interstate waters, and it should have far-reaching effect on stream pollution control in other states having similar problems, as well as in the three states directly affected.

JAMES H. LE VAN

## STREAM CLEANSING IN OREGON

### A Symposium

*Civil Engineering*, 6, 678 (October, 1936)

**At the Portland, Ore.,** Convention of the American Society of Civil Engineers, three papers were presented before the Sanitary Engineering Division on July 16, 1936. These papers are abstracted in Civil Engineering as cited.

Past and Present Efforts to Reduce Pollution, by R. E. Koon, Consulting Engineer

In Oregon the emphasis in stream pollution abatement is upon the protection of recreational facilities. Existing laws are found too drastic and the State Planning Board has given study to drafting a suitable substitute. However, one conclusion in this is:

"A consideration of the legal aspects of stream pollution precipitates a study of the chaotic character of legislative attempts to control a vexatious problem of ever-increasing importance. The welter of conflicting statutes and doctrines of the common law aggravates the perplexity of the problem by failure to accept the irrefutable tenet that ultimate purification cannot be attained overnight through legislative or judicial fiat. Major considerations of a practical and highly technical nature are inappropriately approached by legislative assemblies and courts, and, in the final analysis, the rigid application of legal rules must be fashioned to yield elastically to practical necessities of the situation in hand."

Several studies of river pollution have been made including (1) a report by Hommon on Willamette Valley conditions, (2) "Control of Stream Pollution in Oregon," Rogers and Langton, (3) the results of a sanitary survey of the Willamette River by Rogers and Moekmore, (4) report by Dieck, Cunningham and Koon on sanitary conditions in the Willamette Valley, and (5) report by the Engineering Experiment Station, Oregon State College on the effect of sulphite pulp and paper wastes on Willamette River water.

There are now about 40 sewage treatment plants in Oregon with 13 classed as adequate. Revenue bonds to correct harbor pollution by treating the sewage of Portland have been authorized but not issued.

Present Status of Municipal Sewage Treatment. By Carl E. Green, State Sanitary Engineer

There are 81 municipal sewer systems for incorporated areas in Oregon—30 with treatment works. Additional there are 13 community or institutional plants. Complete treatment is sometimes needed during low flow periods, but primary treatment is generally adequate. Most of the works are in the Willamette Valley where the greater part of the urban population is located.

Most of the efficient treatment plants have been built during recent years aided by federal funds. Assessments, general levies and rentals have been used as the basis for financing. The last of these is the most popular with the rentals determined as flat rates, or from water consumption, or on a fixture basis. The author suggests assessments for the sewers and rentals for the construction and operation of the treatment works.

Plants built thus far have utilized biological processes. Three activated sludge plants (Medford, Burns and Hillsboro) are soon to be in operation. Rotary distributors for trickling filters are used widely including new plants at Ashland, Baker, Gresham, Lakeview, Warm Springs and Multnomah. For primary treatment, mechanically cleaned clarifiers are preferred although Imhoff tanks have been built at Ashland and Talent where

topographical conditions are favorable. Separate sludge digestion and use of the gas for heating and incinerating are common. Sludge is dried on sand beds.

The Multnomah County Farm (650 people) is served by a sedimentation-separate digestion-rotary distributor filter-final tank plant that is operated entirely by gravity. Sludge is transferred from the primary tank by withdrawing supernatant from the digester to the final settling tank. Sludge from the final tank is returned to the primary tank by means of an injector driven from the water supply at 85 pounds pressure. A vacuum breaker is installed in the water supply line.

Cost figures are—primary treatment $6.64 per capita (4 cities); complete treatment $11.90 per capita (11 cities). These costs are for plants only and do not include federal grants. For operation—without pumping—primary treatment costs $0.22 per capita and complete treatment $0.55.

### Industrial Wastes in the Willamette Valley, By Fred Merryfield, Asst. Prof. Oregon State College

The Willamette River is the most polluted river in Oregon. Summer rainfall is light and the river flow decreases steadily to a minimum of 4000 c.f.s. at Salem. Industrial pollution from pulp mills, creameries, woolen mills, tanneries, etc., is distributed over the year, but cannery and flax retting wastes are seasonal and reach a peak during low river flows. In result the oxygen content of the river is seriously depleted 68 miles above Portland and grows progressively worse downstream.

The chief value of the Willamette is recreational, but the headwaters are spawning grounds for salmon which is the basis of a valuable industry.

Wastes from pulp and paper mills include 2000 gallons of sulphite liquor per ton of pulp with variable quantities of white water and bleach liquor. Four mills within the Portland-Salem reach of the river have a (total) average pulp capacity of 300 tons per day.

Flax retting consists in soaking flax in water at 70 to 90 deg. F. The soaking continues 5–10 days, fresh water being added daily. The process is one of anaerobic decomposition of pectose. About 5300 gallons of retting wastes are discharged per ton of flax straw. Some 16 mg. of these wastes are discharged to the river each season.

Pollution loads are shown by the following table:

*Strength of Industrial Wastes, in Parts per Million of Plant Effluent*

| Industry | Waste | B.O.D. | | Solids | | | pH |
|---|---|---|---|---|---|---|---|
| | | 5-Day | 20-Day | Total | Susp. | Diss. | |
| Cannery | Pear | 590 | 1,630 | 4,040 | 200 | 3,840 | 6.40 |
| | Pumpkin | 210 | 515 | 667 | 129 | 538 | 4.41 |
| | Carrots | 1,630 | 2,900 | 5,270 | 2,520 | 2,730 | 5.0 |
| Tannery | Tannery | 1,780 | 2,960 | 21,640 | 1,310 | 20,330 | 10.4 |
| Packing | Meat packing | 1,300 | 22,500 | 2,360 | 780 | 1,580 | 6.56 |
| | Dissolved | 1,000 | 1,400 | — | — | — | — |
| Woolen | Wool scouring | 13,000 | 21,800 | 51,000 | — | — | 9.0 |
| | Wool finishing | 1,420 | 3,850 | 13,560 | — | — | 9.1 |
| Flax | Retting | 2,700 | 5,300 | 4,200 | — | 4,200 | 4.8 |
| Paper Mill | Sulfite lqr | 8,760 | 16,400 | 90,400 | 150 | 90,250 | 5.45 |
| | Bleach lqr | 20 | 62 | 574 | 52 | 522 | 6.47 |
| | White water | 28 | 71 | 242 | 134 | 108 | 5.57 |

Treatment of paper and pulp wastes in "save alls" minimizes the loss of fibre. Experimental work indicates that precipitation with 0.5 per cent lime—222 lbs. per ton of flax—will reduce the waste from 130 to 75 pounds of oxygen per ton of flax straw. Cannery wastes offer a serious problem and a field for possible recovery of values. Screening has been tried with disposal of offal by spreading over the ground. This is costly. Pilot plant studies of treatment of industrial wastes are advocated.

FRANK TOLLES

## SEWAGE TREATMENT IN NEW YORK CITY

BY WALTER D. BINGER AND RICHARD H. GOULD

*Civil Engineer*, 6, 789 (December, 1936)

The article cited is itself a five-page abstract of a paper delivered before the Metropolitan Section American Society of Civil Engineers on March 18, 1936, by Messrs. Binger and Gould, respectively Deputy Commissioner, and Chief Engineer, Bureau of Sewage Disposal, Department of Sanitation, New York, N. Y.

Sewerage in New York was begun in 1696, but the greater portion dates from 1840 following the introduction of Croton Water. Discharge is into abutting waters where tidal movements and the discharge of rivers cause thorough mixing. However, the harbor currents do not sweep clean, and sewage materials move back and forth, with large portions deposited in slack water. In turn this, over the years, has led to general but not uniform reduction of D.O. and to offensive conditions in certain locations. The daily addition of sewage varies from 0.12 to 4.01 per cent of the volume of dilution water. B.O.D. of harbor waters varies between 0.94 and 2.65 and D.O. (for 1934) varies from 5 to 55 per cent saturation.

Pollution conditions in New York waters have been the subject of much study, notably by the Metropolitan Sewerage Commission (Final Report 1914) and by Black and Phelps. In 1929 sewage disposal—previously a local or borough function—was placed under the Department of Sanitation. Sewage treatment at this time was limited to "eight old plants of doubtful value" and to eight fine screen plants which "remove about 1½ per cent of the solids" from the sewage of about one-fifth the people (1,400,000 people of 7,000,000 total). Between 1929 and 1935 the structures of the (180 m.g.d. present, 426 m.g.d. ultimate) Wards Island plant were built, but these are not equipped nor are they connected. Also in 1935 the Coney Island plant (35 m.g.d. present, 140 m.g.d. ultimate) was placed into operation; further, there is now nearing completion a system of intercepting sewers for Manhattan and the Bronx.

The problem of sewage treatment for New York varies with the locality, but generally it is a problem of remedying offensive or unsightly conditions and of recovering former recreational facilities. Bathing, for example, is now permitted only at relatively few outlying points, and some of these are threatened. Apart from the generality, no pollution standards have been set other than by the Metropolitan Sewerage Commission in 1914, thus—

"1. Garbage, offal, or solid matter recognizable as of sewage origin shall not be visible in any of the harbor waters.

2. Marked discoloration, or turbidity, due to sewage or trade wastes, effervescence, oily sleek, odor, or deposits shall not occur except perhaps in the immediate vicinity of sewer outfalls, and then only to such an extent and in such places as may be permitted by the authority having jurisdiction over the sanitary condition of the harbor.

3. The discharge of sewage shall not materially contribute to the formation of deposits injurious to navigation.

4. Except in the immediate vicinity of docks and piers and sewer outfalls, the dissolved oxygen in the water shall not fall below 3.0 c.c. per liter of water. Near docks and piers there should always be sufficient oxygen in the water to prevent nuisance from odors.

5. The quality of water at points suitable for bathing and oyster culture should conform substantially as to bacterial purity to a drinking water standard. It

> is not practicable to maintain so high a standard in any part of the harbor north of the Narrows, or in the Arthur Kill. In the lower bay and elsewhere bathing and the taking of shellfish cannot be considered free from danger of disease within a mile of a sewer outfall."

It is stated that these standards are not inconsistent with the terms of the act which created the Interstate Sanitation Commission which represents common interests of New York, New Jersey and Connecticut.

The present effort of the Department of Sanitation is educational and directed toward obtaining funds. Although no final comprehensive plan has yet been developed, the program includes the possibility of some 38 different plants ranging in ultimate capacity from 1 m.g.d. (City Island) to 426 m.g.d. (Wards Island) and ultimately treating some 1,765 m.g.d. in aggregate. This program might cost up to 200 million dollars. The Department is advocating a five-year 100 million dollar program. At present designs for two of the larger plants—Tallmans Island (70 m.g.d. ultimate) and Jamaica (130 m.g.d. ultimate)—have been authorized. Funds have been requested to enable developing a general plan.

A map which accompanies the article may be read to the effect that of the total ultimate city sewage 27 per cent will be given preliminary treatment in 19 different plants; 33 per cent will be given partial treatment in 13 plants; and 40 per cent will be treated completely in 6 plants.

The article cited includes certain notes on existing and proposed plants, as follows:

*Wards Island.*—The plant under construction is for the activated sludge process. This type of treatment was chosen because plant discharge is into the restricted waters of East River which is purely tidal, and for the further reason that the effects of high degree treatment of a large quantity of sewage at this point will be felt throughout the harbor. Sludge will be barged to sea. Plant and interceptors and connecting tunnels are estimated to cost about $28,000,000. Operation in 1937 is expected. Design capacity is 180 m.g.d.; ultimate 426 m.g.d.

*Coney Island.*—This plant provides sedimentation treatment during the winter and chemical precipitation plus chlorination during the bathing season and to meet the needs of what is termed "perhaps the most frequented strip of beach in the world." Because the site is ice locked during the winter, barging of sludge throughout the year is impracticable, so, at this plant, sludge is digested. Sewage gas is used in combustion engines for pumping. Digested sludge will be dewatered by vacuum filters and will be used for top dressing park and filled areas. Fills adjacent to the waterfront will be dressed with liquid sludge pumped from barges. Design capacity is 35 m.g.d.; ultimate 140 m.g.d.

*Tallmans Island.*—This will be an activated sludge plant for contract 1936–37.

*Jamaica.*—This plant serves an area that is tributary to land locked waters of recreational value. The location and limited tidal circulation have led to the adoption of the activated sludge process for this plant but with preliminary settling displaced by fine screening—fine screens already being in use at this site.

FRANK TOLLES

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## REFERENCES TO SEWAGE LITERATURE

(October and November, 1936)

### American City

*October.*

"Billing and Collecting Sewer Rentals," pp. 47–48.

"Installing Sewer Outfall on Soft Foundation." D. L. McLean, pp. 63–64.

*November.*

"Primary Treatment of Sewage and Food Products Wastes." T. R. Kendall, pp. 53–55.

"Mechanical Type Activated Sludge Plant for Sewage and Dairy Products Wastes," pp. 59, 61, 63.

## Canadian Engineer

*September 29.*

"Sewage Disposal Plant at Burwash, Ont." E. M. Proctor, pp. 3–5.

"Chemical Precipitation Tests at Kitchener Sewage Disposal Plant." S. Shupe, pp. 11–12.

*October 6.*

"Design and Operation of Disposal Plants for Small Municipalities." W. B. Redfern, pp. 48, 50, 52, 54, 56.

*October 27.*

"North Toronto Sewage Disposal Plant," p. 12.

## Engineering News-Record

*October 8.*

"Domestic Wastes Treated in Industrial Sewage Plant," pp. 506–507.

*October 15.*

"Sewage Treatment for Denver," pp. 535–539.

*October 22.*

"Current Notes on Sewage Disposal." W. Rudolfs, p. 589.

*November 5.*

"Industrial Waste Pollution Surveyed," pp. 636–637.

"Water Pollution Control Discussed at Public Health Meeting," p. 654.

*November 19.*

"Chicago's Sewer Tunnels," pp. 703–708.

"Mid-West Sewage Meeting Features Research and Design," p. 713.

"Venturi Measurement of Raw and Digested Sludge," pp. 714–715.

"Current Notes on Sewage Disposal." W. Rudolfs, p. 721.

## Municipal Sanitation

*October.*

"Selling Sewage Treatment to the Public." G. V. Radebaugh, pp. 340–343.

"Palo Alto's 3-Point Operation Program." J. Kimball, pp. 344–346.

"Wrought Iron in Sewage Treatment Plants." B. D. Landes, pp. 347–349.

"Oxidation of Sewage by Activated Sludge." P. D. McNamee, pp. 340–361.

"The Treatment of Beet Sugar Wastes." E. F. Eldridge, pp. 350–352.

"Laboratory Control of Sewage Treatment. Part IV. Sewage Solids." F. W. Gilcreas, pp. 353–355.

"Many Difficulties Encountered in Driving Large Sewer Tunnel," p. 355.

"Status of Sewage and Industrial Waste Treatment in U. S." "California," C. G. Gillespie. "Washington," R. M. Harris, pp. 356–357.

*November.*

"Dover Combines Sewage Treatment and Refuse Incineration." F. S. Friel, pp. 378–381.

"Los Angeles Legalizes Disposal of Ground Wastes into Sewer Systems." L. Aldrich, p. 381.

"The Selection and Care of Gas Engines." W. B. Walraven, pp. 382–386.

"Aurora Sanitary District Installing Gas Engines," p. 386.

"Sulphur Base Cements Protect Sewage Works." C. R. Payne, pp. 387–389.

"Cold Weather Sludge Gas Production." H. W. Taylor, pp. 390–392.

"Laboratory Control of Sewage Treatment. V. Sewage Sludge." F. W. Gilcreas, pp. 393–394.

"Status of Sewage and Industrial Wastes Disposal in the U. S." "Rhode Island," W. J. Shea, pp. 395–396.

"Sewage Treatment Shows Progress Throughout Dominion of Canada," p. 403.

## Public Works

*October.*

"Operation of Separate Sludge Digestion Plants." W. W. Towne, pp. 9–10.
"The Present Status of Textile Waste Treatment," pp. 16–18.
"Drainage for Mosquito Eradication," pp. 21–22.
"Oskaloosa's Sewage Treatment Plant," p. 25.

*November.*

"Acid-Proof Brick Sewer Construction," p. 12.
"Large Sewer Construction by W.P.A.," p. 23.
"Sewerage Work of the W.P.A.," p. 28.

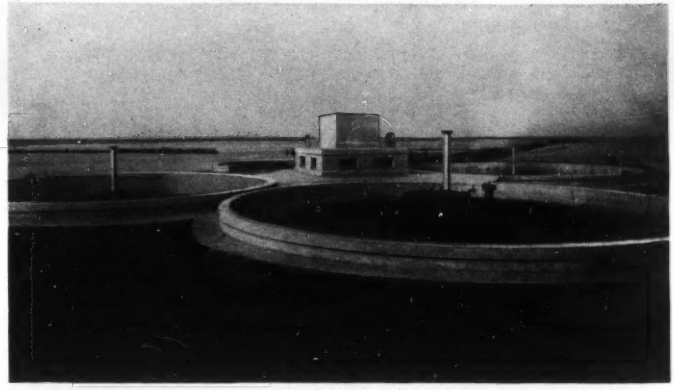
## Water Works and Sewerage

*October.*

"Experiences With Gas Engine Operation." W. B. Walraven, pp. 370–373.

*November.*

"Operation of the Northside Activated Sludge Plant at Durham, N. C." W. M. Franklin, pp. 413–417.
"Running an Activated Sludge Plant on D.O. Determinations." George Andersen, pp. 418–419.
"Battle Creek's New Sewage Treatment Plant." M. G. Damoose, pp. 420–424.
"Digestion of Solids From Pea and Corn Canning Wastes with Sewage Sludge." L. F. Warrick, H. W. Ruf, and J. M. Holderby, pp. 425–428.



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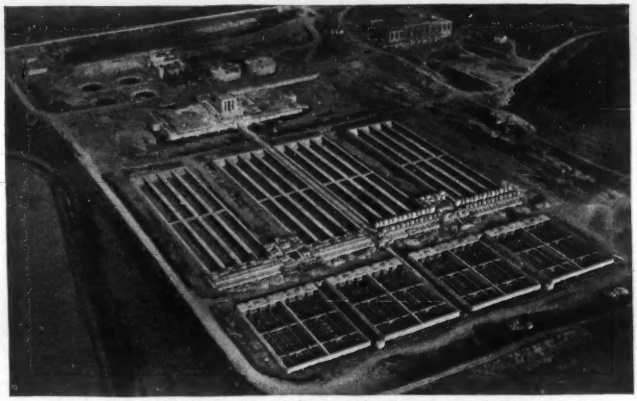

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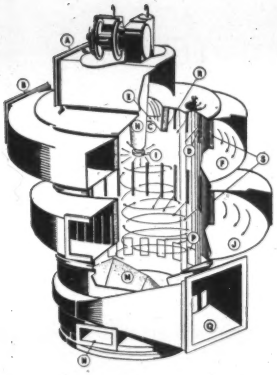

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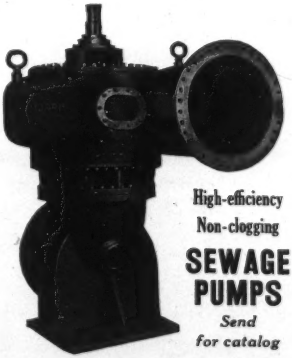

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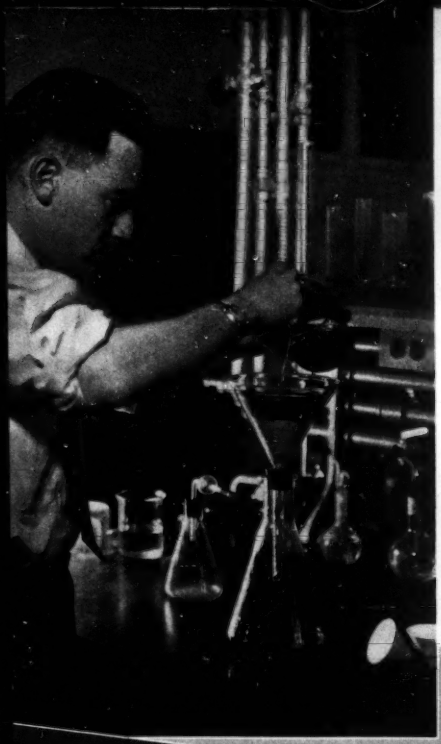

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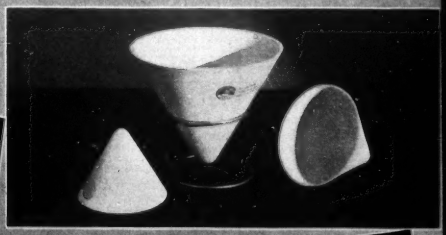

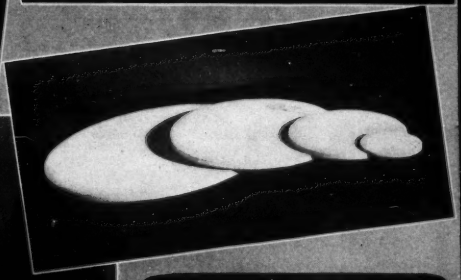

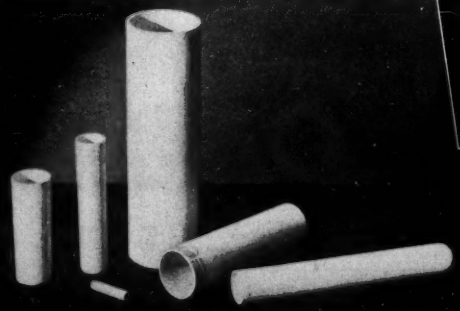

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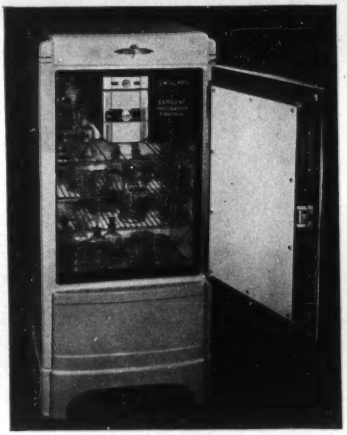

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